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GUIDELINES FOR ROAD ASSET MANAGEMENT SYSTEM

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ABBREVIATIONS

AR	:	Accelerometer Based
ARMS	:	Automatic Rut Measurement System
ARSS	:	Automated Road Survey System
ARUR	:	Automatic Road Unevenness Recorder
AVC	:	Automatic Vehicle Classification
BBD	:	Benkelman Beam Deflection
BPT	:	British Pendulum Tester
CAMBI	:	Car Axle Mounted Bump Integrator
CFMS	:	Continuous Friction Measuring System
FWBI	:	Fifth Wheel Bump Integrator
FWD	:	Falling Weight Deflectometer
GMS	:	Geometry Measurement System
GPR	:	Ground Penetrating Radar
GPS	:	Global Positioning System
LP	:	Laser Profilometer
MPD	:	Mean Profile Depth
PDMS	:	Pavement Distress Measurement System
ROW-VIS	:	Right-of-Way Video Imaging System
SWS	:	Static Weigh Scales
WIM	:	Weigh-In-Motion

GUIDELINES FOR ROAD ASSET MANAGEMENT SYSTEM (RAMS)

1. INTRODUCTION

1.1 Background

The concept of road asset management is becoming increasingly important for those responsible for managing road networks. Degradation to the service level with complete deterioration of road assets cannot be ruled out unless the assets are adequately maintained and managed with scientific approach using various affordable materials, tools and technology. Considering importance of maintenance management of road assets and absence of any standard guideline in our country, it was felt necessary to frame Guidelines on Road Asset Management (RAM) for guidance and adoption by Highway Departments of State/Central Government.

The task of preparation of draft Guidelines on Road Asset Management System was taken up by Road Maintenance and Asset Management (H-6) Committee during the tenure 2012-14. The subgroup under the Chairmanship of Dr. Ashok Kumar comprising Dr. L.R. Kadiyali, Shri D.P. Gupta, Shri S.C. Sharma, Shri Nirmaljit Singh, Shri J.S. Dhanda, Shri R.K. Pandey, Shri Dinesh Kumar, Shri D.C. Dey, Shri K. Sitaramanjaneyulu and Shri M.N. Nagabhushana was formed to prepare the initial draft. Some of the presentations on SoR(s) were discussed during the meetings, however no specific draft could be prepared. Thereafter, the H-6 Committee was reconstituted for the tenure 2015-17, however, not much progress could be achieved on the draft document.

Then the H-6 Committee was reconstituted for the tenure 2018-20 and in its 1st meeting held on 24.02.2018 took this challenge as a priority requirement and started deliberations to draft the RAM guidelines. The IRC and World Bank also jointly organized a workshop during November, 2018 and brainstorming session in October, 2019 to get feedback and experience of various Highway Departments of State/Central Government on Road Asset Management while framing the guidelines.

The draft guidelines were prepared by a subgroup under the Chairmanship of Dr. N.C. Pal comprising Shri D.P. Gupta, Shri Ashok Wasson, Shri K. Sitaramanjaneyulu, Shri M.N. Nagabhushana, Dr. Pradeep Kumar, Shri Neeraj Chadha and Shri Raj Mallela. The modules and systems presently being used by some State Government Departments, NHAI for data collection, data analysis, decision making framework, institutionalization etc. have been appended in the guidelines for reference purpose. Reference from various published literatures/documents on the subject have been made while drafting the guidelines. The draft was deliberated in various meetings of H-6 Committee and was finalized in its meeting held on 11.11.2019.

The composition of H-6 Committee is given below:

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Nagabhushana, M.N.	.....	Member-Secretary

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Secretary General,
Indian Roads Congress
(Basar, Toli), Chief Engineer,
PWD Arunachal Pradesh
(Pandey, I.K.), Ministry of Road
Transport & Highways
Nirmal, Sanjay Kumar

The draft document considered by the HSS Committee in its meeting held on 06.12.2019. The HSS Committee decided that Convenor, H-6 Committee will modify the document based on written comments and verbal comments offered during the meeting and submit the final document to IRC for placing in the Executive Committee (EC) meeting. The EC in its meeting held on 19.12.2019 approved the draft document for placing before the Council. The 219th Council in its meeting held on 19.12.2019 at Patna, Bihar considered and approved "Guidelines for Road Asset Management System" for printing.

1.2 Role of Road Infrastructure in Socio-Economic Development

1.2.1 Roads and road transport constitute a critical component of the transport infrastructure in the country. Roads serve to move people and goods inter-city, intra-city (within urban areas) and in rural areas. Roads influence economic development, population distribution, shape of cities, access to social infrastructure (education and healthcare facilities), markets and enhance quality of life of the people. They contribute to cause increase in GDP (Gross Domestic Product) and provide employment opportunities for millions of people across the country.

1.2.2 The road network in India essentially comprises of National Highways, State Highways, Major District Roads and Rural Roads (Other District Roads and Village Roads). Their development received a push with the launching of 'National Highways Development Project' and 'Pradhan Mantri Gram Sadak Yojana' about two decades back. A study conducted by the National Highways Authority of India on the socio-economic development for the Agra-Kolkata National Highway revealed the following:

- Proximity to highway and its upgrading has significant beneficial influence on major aspects of socio-economic well being of the rural population as greater opportunities of employment and earnings in non-farm activities are generated, access to education and health facilities improves, household incomes rise and so do asset holdings.
- Benefits mostly extend upto a distance of 5 km on either side of the highway and density of population in nearby villages is generally higher due to the rural poor staying close to highway for better non-farm job prospects.

1.2.3 In another study by the World Bank, the Golden Quadrilateral (GQ) NH Project was found to have increased the organised manufacturing of several commodities and articles of use by the people. It improved the connectivity and market accessibility of districts lying close to the GQ. The project also appears to have encouraged decentralisation by making intermediate cities more attractive for manufacturing entrants.

1.2.4 Similarly, the impact of Pradhan Mantri Gram Sadak Yojana has been studied by the Ministry of Rural Development and these studies reveal clearly that the scheme has acted as an instrument of poverty alleviation and an enabler for employment opportunities besides providing boost to agriculture output, agro based industries and farms to markets connectivity. School enrolment has considerably increased and healthcare facilities can be accessed easily by the rural masses.

Box 1 captures some key benefits from sustained access and mobility

Box 1. Benefits from Sustained Access and Mobility

- Owners of vehicles incur lower operation cost
- Users of public transport benefit from reduced travel times, lower fares, better regularity of services.
- Farmers and traders incur lower transport costs and have better business environment.
- Better access to health, education, agriculture extension services.
- Provides improved access to employment opportunities and other economic activities.
- Rural roads serve as entry point for poverty alleviation. They also provide physical mobility of raw materials, farm produce, promote specialisation and increased size of market and help in reduction of inequalities.

1.2.5 Roads also serve as last mile connectivity to other modes of transport such as links to railway stations, container freight stations, major and minor ports, airports, inland waterway terminals besides providing access to power plants, special economic zones etc.

1.2.6 To sum up, roads become a lifeline to new markets, new businesses, new incomes and above all to new opportunities. Even a narrow road that helps connectivity to village or agriculture market (grameen mandi) can be an instrument of prosperity.

1.3 Importance of Road Maintenance

1.3.1 Road maintenance may be defined as routine work performed to upkeep pavement, shoulders, bridges, culverts, safety and traffic control devices and other ancillary furniture provided for road users, as nearly as possible in their constructed condition under normal conditions of traffic and climate. If not maintained, roads rapidly become impassable for motorized traffic. The pace of deterioration depends upon the quality of initial construction, drainage measures, levels of traffic, loadings and weather conditions.

1.3.2 Poorly maintained roads raise vehicle operating costs and accident rates and can constrain mobility.

1.3.3 Appropriate maintenance intervention for pavement preservation, if ensured at right time, can reduce greenhouse gas emissions as reported in some research publications, where life-cycle assessment study considering carbon dioxide emissions associated with different asphalt preservation treatments have been analysed including emissions generated during the construction stage.

1.3.4 Maintenance of roads serves the following purposes:

i) Reduces the rate of deterioration of the road infrastructure – pavement, cross-drainage structures, traffic control and safety devices, protective structures – thus prolonging the life of different components of road assets and thereby safeguard the huge investments made in construction of new roads and upgradation including capacity augmentation of existing roads. This also helps the government in avoiding premature investment in rehabilitation and reconstruction of the roads and thus enables optimum use of available resources.

ii) Lowers the cost of operating vehicles and fuel consumption and reduces the rate of deterioration of the vehicles, which is of benefit to the road users.

iii) Contributes to provision of more reliable and safe transport services by keeping the road open to traffic without interruption (except of course in the event of any disaster-natural or manmade).

iv) Helps in ensuring social and economic benefits of road access and mobility being available on a sustained basis.

1.3.5 No matter what technical design and standards are adopted, all roads, irrespective of class and volume of traffic carried, require regular and timely maintenance to serve the intended purpose. These in turn require adequate funding and institutional arrangement for effective planning and delivery of maintenance interventions. A well maintained road also enhances the image of the road authority as also that of the state and the country.

1.4 Road Asset Management

1.4.1 It is a strategic and systematic process of maintaining, upgrading and operating road assets throughout their life-cycle in a cost effective manner by combining engineering principles with business practices and economic theory.

1.4.2 The rationale and key objectives of ensuring management of road assets can be described as under:

i) Preserve the existing road assets so as to reduce the potential losses in value of these assets by ensuring timely, regular and adequate maintenance.

ii) Link funding with performance of the assets and achieve value for money invested in asset creation and upgradation.

iii) Move towards outcome based results to ensure economic benefits to vehicle operators and other road users.

iv) Decision for various interventions be based on asset management principles and data on condition of the network being updated regularly.

1.4.3 The journey to Asset Management has been pictorially explained in the flow chart shown at **Fig. 1**.

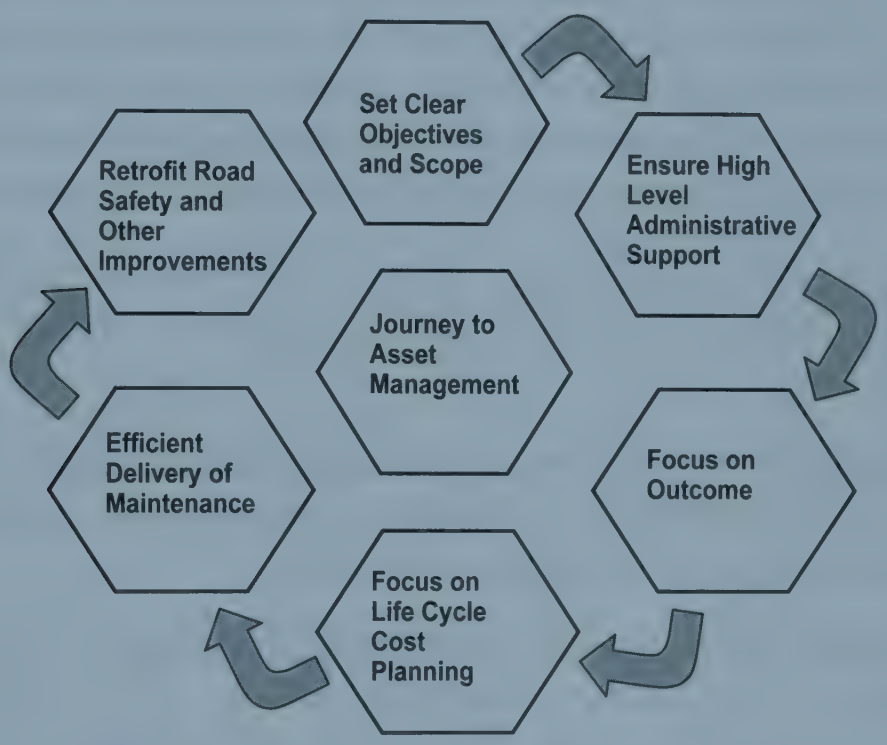
Set Clear Objectives and Scope
Ensure High Level Administrative Support
Focus on Outcome
Focus on Life Cycle Cost Planning
Efficient Delivery of Maintenance
Retrofit Road Safety and Other Improvements
Journey to Asset Management

Fig.1 Flow chart on journey to Asset Management

1.5 Rationale for Road Asset Management

1.5.1 The practice of road asset management, which involves monitoring of asset performance and selection of cost effective preservation actions over facility life, is needed at the current time due to recent and ongoing development in the road network, increasing commercial and personal travel demand, higher user expectations of levels of service, increased stakeholder participation in decision-making, greater need for transparency and accountability, and limited funding for preservation and expansion of road assets.

1.5.2 In a bid to address the needs of the road affected community, the road authorities at all levels of Government (national, state, district, etc.) face the task of effectively managing their road assets so as to ensure acceptable functional condition, satisfactory levels of service, and minimal environmental damage within available resources. Given the importance and typically huge expense of road assets, and the dominant share of Government budgets, they command for expansion and preservation, it is critical that such assets are strategically managed in a way, that is not only cost-effective but also integrates the different components of the road network.

An explicit asset management system would assist road authorities in effectively and efficiently carrying out the business processes of resource allocation and utilization, evaluation and decision-making. At the current time of constrained resources and increased public scrutiny of agency investment and budget decisions, the application of asset management is all too critical.

2. SCOPE OF THE GUIDELINES

2.1 Present Guidelines are intended to guide the Highway Organizations at State and Central Government level to follow step by step procedures in implementing management of road assets considering principles of sound engineering and economics theory besides use of modern IT-ICT tools.

2.2 The Guidelines provide valuable information on pavement performance analysis, pavement condition assessment with various data collection equipment, analytical tools for data analysis to predict road network condition based on alternative maintenance strategy, asset management implementation modalities with parameters for monitoring and evaluation besides web based thematic mapping of asset data on GIS (Geographic Information System) platform using modern IT tools/strategy to facilitate sharing information in public domain.

2.3 The Guidelines will assist all State Government/Central Government/other Highway Authorities/Agencies to implement Road Asset Management (RAM) considering common "ground rules and terminology".

2.4 The Guidelines promote a deeper understanding of asset management principles that will enable Highway Authorities to demonstrate prudent stewardship of their assets and better justify funding decisions both nationally and locally.

2.5 Present Guidelines emphasizes on use of PMS tools with inbuilt deterioration modelling in predicting road condition as per traffic projections with life cycle analysis considering various alternative maintenance strategy and cost interventions to facilitate organization in optimising maintenance and operational expenses besides proper assessment of financial parameters for the road project/bundle of road projects being awarded under OMT (Operate-Maintenance-Transfer) or TOT (Toll-Operate-Transfer) concession mode.

2.6 Case studies of some State/Central Government Organizations, where Road Asset Management Systems (RAMS) have been developed/commissioned and are already being implemented with proper institutional arrangements have been given in the Appendices for reference and guidance purpose only. The information contained therein with respect to data collection, use of modern survey equipment, data analysis with planning tools, data storage and data management with web based application for reporting and monitoring, use of IT-ICT tools with system architecture as implemented, institutional arrangement etc. shall able to provide enough confidence among the Road Authorities working with various State Government and Central Government in implementing RAMS in their respective organization.

2.7 Scope of the present Guidelines is limited to Management of Road Assets only and does not cover Bridge Assets, although Bridges are also essential vital link in any Highway Network System and are valuable assets which cannot be built and just forgotten.

3. PRINCIPLES OF ASSET MANAGEMENT

3.1 Core Principles of Asset Management

Road Asset Management is a systematic process of maintaining, upgrading and operating physical assets in a cost-effective manner by combining engineering principles with sound business practices and economic theory. It provides tools to facilitate organized and logical approaches to decision-making, which facilitate to achieve the public's expectations under Government plans and policies. In helping the road asset manager to carry out the tasks as implied above, there often exists a set of core principles that drive the practice of road asset management. These are:

- Road Asset Management (RAM) must be driven by agency policy – resource allocation decisions should be based on a well-defined set of policy goals and objectives that reflect the mission or vision of the road agency/department. These often include goals that are related directly to the agency (e.g., system condition), the highway user (e.g., delay, safety), and the community (air quality, noise, economic development, etc.).
- Road Asset Management (RAM) must be performance-based – the highway agency's policy objectives must be translated into system performance measures for purposes of tactical (day-to-day) as well as strategic management.
- Road Asset Management (RAM) must facilitate the analysis of investment options and must help the agency in making decisions on how to allocate funds across different asset types (pavements, bridges, safety hardware, etc.), and also to quickly and interactively investigate the trade-offs between different funding levels and performance in the component management systems, and also between the different performance measures for a given funding level. The investigation of "lower-level" trade-offs (such as preventive maintenance versus rehabilitation, capacity expansion versus operations, etc.) are carried out at the level of the individual management systems.
- Road Asset Management (RAM) must yield decisions that are based on quality information – It should help an agency to examine the merits of different options with respect to an agency's policy goals using data that are reliable, relevant and current. Thus, a good data collection and management process is essential for asset management.
- Road Asset Management (RAM) must enable monitoring to provide clear accountability and feedback – This helps in easy access to needed information and in monitoring or predicting asset costs and performance. Feedback on actual performance may influence agency goals and objectives, as well as the methodologies used to allocate resources. This principle is particularly important because there is a continuing trend towards the use of performance based approaches to the highway asset project delivery.

3.2 Benefits of Road Asset Management

Asset management facilitates better decision-making by supplementing engineering judgement and with analysis (financial, economic and engineering). It enables an Authority to better understand and manage the relationship between cost and performance. Benefit Value can be expressed as Performance/Cost of Service Delivery,

Where,

Performance = Σ Level of service; condition, availability, safety etc.

Specific benefits of asset management include; reduced life-cycle costs, defined levels of service, ability to track performance, improved transparency in decision making, ability to predict the consequences of funding decisions.

3.2.1 *Establishment of goals and performance measures*

The practice of road asset management can provide an agency with greater motivation to clearly define its goals and objectives, and consequently, the performance measures needed to ascertain the extent to which the goals are being achieved. In an asset management system, the agency needs to set its network-level goals as well as project-level goals. Also, the goals of the agency from the perspectives of its stakeholders (the agency itself, the highway user, and the community) will need to be defined clearly before the asset management system can be effective.

3.2.2 *Monitoring Assets*

It is essential for road authorities to effectively monitor the physical condition and operations of their assets. Technologies that monitor the condition or performance of critical elements of the highway assets can be deployed to communicate required information to any centralized system for analysis, evaluation and decision for any corrective intervention. Central Planning Unit of any Highway Organization, Traffic Operations and Response Centers, Road Accident Management Data Centers etc. are some examples of such centralized units. Implementation of precise and efficient asset management systems can be done through varying levels of sophistication, depending on the scope, scale and complexity of the systems as per the Organization/Road agency's requirement. In certain cases, there exists real-time and/or online capabilities for asset monitoring and response. At the network level, enhanced monitoring of actual system-wide performance and costs, can yield lessons that can be fed back during the planning phase to improve future decisions.

3.2.3 *Enhanced decision-making due to better analytical tools*

The analytical component of Road Asset Management systems, which includes tools such as optimization, statistical modeling, simulation, multi-objective analysis, and life-cycle based economic analysis, can help an agency prioritize projects for asset preservation for a network of assets, schedule optimal actions over the life of a single facility, and establish optimal funding levels for a network at a given year or over an analysis period. If this is done, agencies can move away from current sub-optimal practice to optimal practice for infrastructure preservation, and in doing so, can obtain lower long-term costs without unduly sacrificing performance, higher cost-effectiveness, maximum use of available funds, and ultimately enhanced credibility and accountability for funding decisions.

Also, enhanced analysis and decision-making can be made when relevant and quality data are available. Data on historical and planned preservation costs (incurred by the agency, user and the community), deterioration rates, and effectiveness of preservation actions, among others, are made available when a fully functioning asset management system is in place. The availability

and accessibility of such data are facilitated when the databases of the different management systems are integrated through an asset management system framework.

3.2.4 *Evaluate decisions based on multiple performance measures*

It is important to assess the impacts of a planned asset preservation project on the basis of several different impacts of the project using an asset management framework. For example, a pavement project may have impacts not only on pavement preservation, but also on safety (skid resistance) and capacity enhancement (if it involves lane addition). In this regard, the benefit of an asset management system is consistent with other stated benefits because use is made of the multiple goals and performance measures established as part of the agency's mission, and the concerns of stakeholders can be better incorporated in agency decision-making.

3.2.5 *Enhancement of intra-agency communication and interaction*

Asset management, when effectively practiced, covers almost every organization level and functional area of a highway agency such as planning, engineering, finance, programming, construction, maintenance, and information management. A properly functioning asset management system encourages communication between managers and personnel at the various functional areas, the asset types, and hierarchical levels. For example, the manager in charge of pavement asset design "talks" with the Engineer in the bridge maintenance area to examine how enhanced design could reduce the intensity and frequency of bridge deck maintenance. Also, asset management fosters proactive rather than reactive approaches to asset preservation problems, as preventive maintenance is given a visible role in an effective asset management framework. Strong top-down and bottom-up communication that are characteristic of good asset management systems ensures that strategic decisions are well informed by tactical information, and that tactical decisions are aligned with strategic direction. Also, it provides avenues for the coordination of interdisciplinary decisions across different agency divisions. Asset management can enhance accountability for decisions and subsequently, system performance.

Thus the benefits that a road agency can expect to reap by implementing Road Asset Management System (RAMS) include an explicit establishment of goals and performance measures, monitoring of asset condition/performance, assessing hypothetical planning scenarios and inclusion of stakeholder concerns, enhanced decision-making due to better tools, opportunity to integrate decisions in the different management systems, opportunity to evaluate decisions on the basis of multiple performance measures and enhancement of intra-agency communication and interaction. Pictorial representation on Benefits of Road Asset Management System is shown at **Fig. 2**.

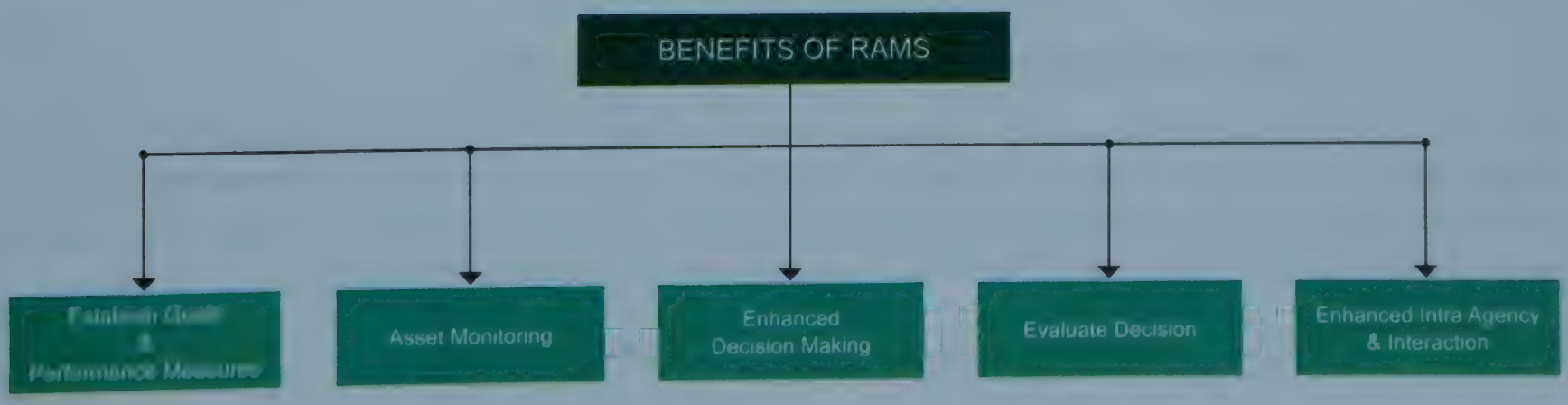

Fig. 2 Benefits of Road Asset Management System

3.3 Components of Road Assets

Road pavement, shoulder, berm, embankment, road side drains, protective works, footpaths, road furniture, cross-drainage structures, guard post, railing, fencing, boundary pillars safety features, etc. are all components of road assets.

3.4 Asset Valuation and Depreciation

3.4.1 Assessing the asset value of highway infrastructure is a complex task with multiple dimensions. There are social, environmental, aesthetic, and political aspects of infrastructure's asset value as well as the more conventionally understood economic and financial dimensions. Then there are variations in condition and width of roads and bridges and unit cost of construction, upgradation etc. across districts/states.

3.4.2 Four basic approaches generally adopted for asset valuation are:

a) historic cost (what was paid in the first place),
b) replacement cost (what it might cost to replace),
c) perpetual inventory (what it is worth "as is"), and
d) discounted value approaches (what one might be willing to pay not to lose it)

3.4.3 The valuation of highway assets is expected to ensure accountability of road authorities who are the owners of these assets, enabling an assessment of loss of assets base, if any over time thus providing budget justification in maintaining the assets base. Furthermore, agencies can be provided greater impetus for establishing a common framework for developing a comprehensive database for condition and inventory survey of various components of road assets: pavement, cross drainage works, protective works, traffic control devices and other road furniture etc. Through such developments, it is expected that highway asset management will provide transport support services to road users in more cost effective manner. It is also envisaged that adherence to asset valuation principles would foster enhanced planning, design, and maintenance of highway assets to provide maximum possible levels of service.

3.4.4 From the highway financing perspective, one of the expectations could be that bond financing for highway assets might become increasingly feasible as the value of the assets become known and predictions of life-cycle benefits and costs become more reliable, and that highway agencies will be in a better position to infuse private-sector financial discipline into the management of their assets. Finally, as the public sector gets more and more involved in highway asset management through outsourcing of line functions, financial participation, or possible asset ownership or operation, overall costs could be lowered.

3.5 Possible Approaches for Valuation of Road Assets

The two common approaches for highway asset valuation are a) the depreciation approach (with which the historical cost of asset is adjusted in accordance with accepted depreciation methods) and b) the modified replacement cost approach that takes into account the inventory and condition of the road. Both these approaches are described here under.

3.5.1 *The Depreciation Approach for Highway Asset Valuation*

Every component of road, whether embankment, pavements, bridges and culverts, protective works (breast walls, retaining walls, guard rails), traffic control devices, has a certain design

service life and would need upgradation at the end of the design life. Normally component of land for the road is not counted towards valuation of roads assets as the road is attached to the earth.

Depreciation is the progressive decrease in value of a physical asset as a result of wear and tear over time. Depreciation is important in highway asset management because of its accounting significance. Specifically, depreciation establishes an annual deduction of asset values such that the effect of time and use on an asset's value can be reflected in a firm's financial statement as a cost depreciable. An asset must meet the following basic accounting requirements: (i) it must be used in business or held to produce income, (ii) it must have a determinable useful life, (iii) it must be something that wears out, decays, gets used up, becomes obsolete, or loses value with time.

3.5.1.1 The depreciation approach for highway asset valuation assumes gradual deterioration of the asset over its service life and consequently reduces the recorded value of the asset on the balance sheet through depreciation. In this approach, initial construction, improvement, and preservation costs are capitalized while maintenance is considered as an expense. The current value of the asset is established using an appropriate deterioration function for various components of the road assets. The depreciation approach requires data such as initial costs, estimated salvage value, expected service life, current age of the asset, and remaining service life. Depreciation takes into account the decrease in the service potential of capital assets invested in a business venture, resulting from such causes as physical wear and tear in normal use, deterioration due to effect of weather condition or they become inadequate for needs of traffic. The common depreciation methods include straight line, sum-of-years digits, and double declining balance.

3.5.1.2 The amount of depreciation over the entire life of an asset is the difference between initial asset value and the value at the end of its service life. At any given year within the service life of the asset, the remaining value of the asset (often referred to as the "book" value), is the difference between initial value and the accumulated depreciation as of that year. The book value of an asset at the end of its service life is the salvage value. To obviate the accounting problems and biases introduced by the changing value of money of time, it is prudent to convert the assets initial value and salvage value in constant rupee terms. The mathematical relationships between initial value, salvage value, and book value are shown in Equation below:

$$D = P - S$$

Where

D = total depreciation over the analysis period;

P = Initial value of the asset;

S = Salvage value of the asset i.e., value of the asset at the end of the analysis period)

$$B = P - D$$

Where

B = Book value at any Year; P = Initial value; D = Depreciation.

3.5.1.3 The pattern of depreciation of an asset depends on a variety of factors such as the asset type, design and material type, level of usage, climatic conditions, and inputs of maintenance (routine, periodic and emergency).

3.5.2 *Modified Replacement Cost Approach*

There are a few basic requirements of data and information to be collected to be able to make an assessment of road assets using the modified replacement cost approaches, these are:

i. Condition of the road and its cross-sectional details

ii. Condition of cross drainage structures

iii. Condition of other components such as traffic control devices (road signs, pavement markings, delineators, guard rails, crash barriers etc.)

iv. Unit cost of various components of the road in question if these components were to be provided now as per the original standard i.e. in good condition.

v. Unit cost of improvement required for various components of the road in question if they are now in fair or poor condition and these are to be brought in good condition.

3.5.2.1 This approach does not consider as to what was the actual initial cost of providing the road assets. Rather, the approach is to estimate the cost involved in replacing the existing road as per the condition in which it is found at the time of valuation of the assets. The present worth of the road in fair condition is induced cost in good condition minus the cost required for bringing the road to initial standards.

An example is given to illustrate the approach.

Example: The road is four lane, 40 km in length with cross drainage structures, traffic control devices and other safety engineering measures, protective works. Now the condition of road is good to very good in a length of 25 km, fair in a length of 5 km and poor in a length of 10 km at the time of assets valuation. By considering, the unit cost of providing/constructing the road as per initial standards would be Rs 8.0 crore per km, unit costs of bringing the roads from fair to good condition would be say Rs. 1.2 crore and from poor or very poor to good condition would be say Rs. 5.0 crore per km. In this case, the present worth of the road in fair condition is Rs. (8.0-1.2) = Rs. 6.8 crore per km and that of the road in poor/very poor condition is Rs. (8.0-5.0) = Rs. 3.0 crore per km. The replacement cost of this road would be computed as under:

i. If the entire road would be in good condition, the replacement value would be Rs. (40x8.0)= Rs. 320.0 crore.

ii. However, only 25 km are in good condition.

iii. For the section of road in fair condition (5 km), it would require Rs. (5x1.2) = Rs. 6.0 crore to bring it to initial standards and for the section of road in poor to very good condition (10 km), it would require Rs. (10x5) = Rs. 50.0 crore to bring it to initial standards.

iv. Thus, in this example, an amount of Rs. 56.0 crore would be required for bringing the road into its initial standards. The replacement value in current situation shall be Rs. (320.0 - 56.0) = Rs. 264.0 crore. This is the replacement value of road and represents the present worth or in other words the asset value as per this approach.

3.5.2.2 It is proposed that the road authorities may consider adopting the modified replacement cost approach in valuation of road assets as it represents a combination of both what it might cost to replace and what it is now worth on "as- is" and "where is" basis.

4. ASSET MANAGEMENT IMPLEMENTATION MODALITY

4.1 Implementation Concepts

Embedded in the definitions of asset management are the concepts that reflect the fundamental nature and goals of highway asset management. Basically three step procedures are given for asset management namely; **Input** (i.e. required data for road asset management systems, **Tools** to run asset management which involves the use of data management, statistical analysis, simulation, optimization, life-cycle costing, multi-criteria analysis, etc. **and desired Output**, which provides asset-wise solutions such as the selection of projects involving from the different management systems under various budgetary scenario, analysis of highway performance. There is no one single solution for all asset management problems. Indeed, there exist several possible ways to implement good practices in asset management by enabling the agency to refine the concept in the way that best suits its mission or business processes. Overall, asset management can be described as a set of best practice methods involving engineering, finance, and economics for cost-effective resource allocation and trade-off investigation across the component management systems. Thus, asset management offers an opportunity for an agency to quickly view, for its highway assets, the impact of different resource allocation levels and the resulting performance in a comprehensive and interactive manner

The agency missions may include:

- To plan, construct, operate, and preserve road assets in a cost-effective manner;
- To deliver value for money to the road users; and
- To ensure that the surrounding community is not unduly disrupted or inequitably burdened with externalities arising from the construction, operations, or maintenance of the asset;
- To enhance the credibility and accountability of the highway authority to the general public and legislative bodies.

4.2 Review of Current Practice and Gap Analysis

All highway authorities practice several elements of asset management in some form. It is therefore advisable to study current practice and compare it with an asset management approach. In doing so the issues on **"what, why & who benefit"** from asset management should be explicitly considered as explained below.

a) Does the current organisational structure allow the use of asset management?
b) Do the key personnel have the skills required to implement asset management?
c) How is asset information disseminated?
d) How are political influences catered for in current decision making?
e) How are annual budgets set?

f) What cognisance is taken of asset condition and performance data in establishing the need for resources and the distribution of available resources?

g) Do budgets reflect levels of service?

h) To what extent does performance against established levels of service affect resource allocation?

i) How are alternative options evaluated?

j) The application of whole life costing requires alternative solutions and treatments to be identified and compared with each other.

k) Are the best whole life options identified?

l) What analysis is carried out? For example – are economic evaluation techniques used and the calculation of the net present value of alternative options

m) How are improvement projects identified?

n) Is this via a structured process?

o) How are the benefits of projects quantified?

p) Are the expected benefits of projects identified in terms of their effect on levels of service and their effectiveness recorded post completion?

q) How are alternative projects compared?

r) How are competing demands rationalised?

s) How is a decision reached on whether to pursue say street lighting improvement rather than pavement repairs?

t) How are projects prioritised?

u) How are programmes produced and how far forward are programmes planned i.e. how many years?

4.3 Need Assessment

Highway asset maintenance/preservation generally refers to the set of activities (reconstruction, rehabilitation, and maintenance) that are carried out to keep a facility in usable condition until the next reconstruction activity. Need can generally be attributed to investment targeted to address an identified deficiency or maintain/operate existing facilities of the highway network. Need could be backlog or current need or future need. As such, one of the tasks faced by highway asset managers is to determine the preservation needs (physical and monetary) for all the assets in their highway network. Both network-level optimization and needs assessment yield a list of projects that can be explained with justification. However, optimization at the network level shows only the preservation/maintenance work that can be afforded within a given budget or performance constraints. While optimization results are used for fiscal planning and programming, needs assessment are used to assess how much preservation work is needed overall and to help determine what percentage of needed preservation work is (or will be) carried out under the historical or expected spending levels or under optimal spending levels. From the methodology perspective, needs assessment can be considered a more specific case of network-level optimization where there are no cost or network-level performance constraints.

4.3.1 *Needs Assessment on the Basis of Asset Age*

The age-based approach for needs assessment rests on the premise that the reconstruction or rehabilitation treatments of assets have certain life spans (also referred to as “service life”) that

can be well predicted on the basis of time, and that some activity is needed when the service life is reached. As such, this approach utilizes pre-defined time intervals that are assumed to reflect preservation of service life. The reliability of the age-based approach is governed by the integrity and consistency of the relationship between asset condition and age. Age based approach is relatively easy to use (compared to the performance based approach) because data on primary and secondary ages [years since last (re)construction and rehabilitation, respectively] are relatively easy to obtain. By virtue of its concept, the age-based approach may be considered superior to the historical spending approach, and may be viewed favorably by some practitioners as a convenient approach for needs assessment. However, this approach may have some limitations. First, the reliability of the specified time intervals of preservation application could be questioned, if the asset encounters significant changes in its environment such as improved rehabilitation or maintenance materials and processes, heavier-than-expected or lighter-than-expected loadings, adverse or favorable changes in climatic patterns, etc. Such factors could lead to reduced or increased service life of preservation treatment and consequently, decreased or increased application intervals, and finally, lower or higher needs. Secondly, in the age based approach, it is generally difficult to incorporate new performance measures or modified standards of existing performance measures in the needs estimation process, because the service life of the certain asset classes, from the perspective of the new performance measures is not known.

In the age based approach, the application intervals for asset replacement or rehabilitation may be fixed or variable. In the case of rehabilitation in particular, variable intervals are often used: larger intervals (lower frequency) for relatively young assets, and smaller intervals (higher frequency) for relatively older assets. Application intervals are mostly based on age (time) but could also be based on age-related deterioration factors.

4.3.2 *Needs Assessment on the Basis of Asset Performance Trends and Thresholds*

This approach makes use of a relatively wide array of specific characteristics such as functional (including bridge geometry for example) deficiencies (or trends thereof) to determine when a highway pavement/bridge needs replacement or rehabilitation, structural condition of the pavement/bridge elements, the performance deterioration curve, and pavement/bridge condition trigger values. By prescribing actions on the basis of performance rather than past trends or treatment intervals, the performance based approach overcomes the limitations associated with the age based and historical spending approaches. For example, if an agency adopts more conservative or liberal performance policies in future, the thresholds of the performance measures used in this approach could simply be changed for consistency with the new standards, and the needs estimate can be reassessed. Furthermore, in the current era, where new performance measures are becoming more and more important, the performance based approach is useful because it enables the incorporation of additional performance measures (as well as their thresholds) for purposes of needs assessment. For example, bridge engineers may seek ways to improve bridge structural design and retrofitting treatments to render bridges less vulnerable to failure in face of man-made attacks. Unlike the historical spending approach, the use of the performance based approach is not hampered by the year-to-year fluctuations in past preservation efforts.

Use of the performance based approach requires that the highway agency regularly monitors asset condition or performance as well as the types and volume of traffic that use the asset. Such monitoring can be done in two ways:

4.3.2.1 Desk Monitoring

This refers to the tracking of the condition/performance of the assets using performance models (typically developed for each asset family grouped by functional class, material type and/or some other characteristic). Such performance models are typically derived from field data. In this case, relatively little field monitoring is needed but may be carried out to generate data for development, validation, or updating of the performance models. Such models typically describe asset performance as a function of accumulated environmental stressors and traffic loads and may be developed using a variety of analytical techniques such as statistical regression, Markovian approaches, neural networks, etc.

4.3.2.2 Field Monitoring

This involves direct site inspections of asset condition/performance on a regular and frequent basis. Such monitoring may be carried out using automated equipment or using visual inspection. Field monitoring is considered superior to desk monitoring, because it provides real, not simulated, performance/conditions of the asset and therefore provides a basis for more reliable assessment of functional and structural deficiencies. Thus it is suitable for more precise needs estimates.

4.4 Pavement Deterioration

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions. Deterioration is well understood in case of Flexible/Bituminous pavement, which is known for its durability and resilience. Like all paved surfaces, it too is susceptible to deterioration due to the laws of mother nature. Despite the longevity of a properly laid bituminous pavement, it can be cut short due to poor surface preparation and construction technique or simply long term exposure to the elements. Deterioration of constructed pavement is natural. It's natural because over time, the materials that make up asphalt begin to break down and become affected by elements such as rain, sunlight and chemicals that come into contact with the pavement surface. The liquid asphalt binder that is the "glue" of the pavement begins to lose its natural resistance to water, allowing it to penetrate into and underneath the pavement. Once this happens, the surface can quickly fall prey to a number of different types of deterioration. Deterioration of asphalt pavements can also occur due to factors that go beyond just normal wear and tear. The premature deterioration of bituminous pavements can be due to a number of factors including:

- inadequate compaction of the subgrade,
- poor bituminous mix,
- wrong choice of the bituminous layer,
- inadequate compaction of the bituminous layers resulting in high voids
- insufficient or improperly compacted base below the bituminous layers
- over or under compaction of bituminous layers
- improper temperature of bitumen when applied
- poor drainage

When bituminous pavement is constructed and maintained properly it wears out slowly and can last even up to 20 years. Proper maintenance is key to protecting it from the external factors that wear it out. Factors that cause deterioration in pavement include:

Water - Over time and especially without proper maintenance - water penetrates the bituminous layers and, washes out the base underneath it, causing it to crack, break down and collapse.

Sunlight - Oxidation breaks down and dries out the flexible liquid bitumen that holds the aggregates together. This causes ravelling and shrinking cracks which allow water to penetrate beneath the surface.

Chemical/petroleum exposure - the introduction of chemicals to asphalt, including gas and oil, can soften the asphalt and cause it to break down more rapidly.

The truth is no bituminous layer is exempt from deterioration no matter how well it is constructed wherein, deterioration begins immediately. Even in normal conditions substantial deterioration can begin to take place after 3 to 5 years. It is normal after this amount of time for bituminous material to begin to turn grey, become brittle and start cracking. Water begins entering the cracks, freezes and thaws during the yearly cycle and causes larger cracks and potholes. Rain enters the cracks and causes damage to the base. These all contribute to a worn out bituminous pavement and must be stopped before it's too late.

Below is a list of the different types of bituminous deterioration:

- Cracking - There are many different types of cracking that can occur, which include: alligatoring, edge cracks, slippage (caused by improper compaction), reflection (older cracks occurring in a new overlay), edge joint, shrinkage and widening.
- Distortion - Caused by improper pavement construction, deterioration of the underlying base or existing asphalt and high load factors, asphalt distortions include: channels or ruts, corrugations and shoving, grade depressions, upheaval and utility cut depressions.
- Disintegration - Types of bituminous disintegration include potholes and ravelling.

Pictorial representation on causes and effects of Pavement Deterioration shown at **Fig. 3**

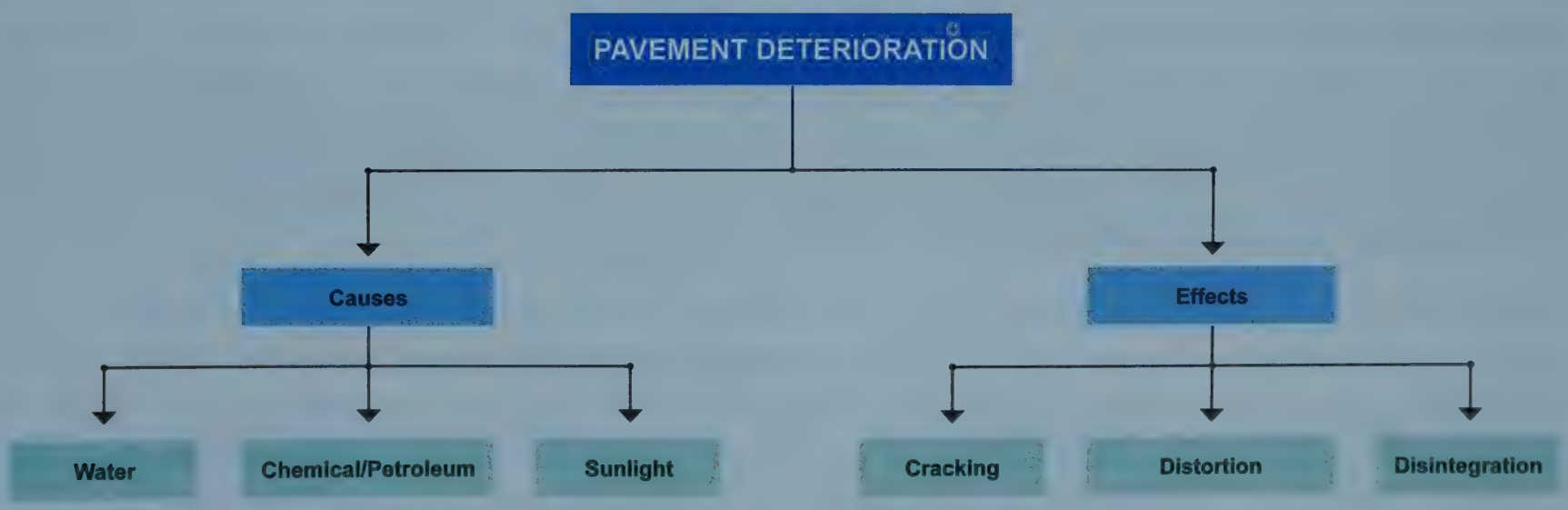

Fig. 3 Causes and Effects of Pavement Deterioration

4.5 Deterioration Modelling and Pavement Performance Evaluation

Pavements are complex physical structures responding in a complex way to the influences of numerous environmental and load-related variables and their interactions. Pavement Deterioration model sometimes referred as Pavement Performance Prediction Model, considers

the evolution of various distresses with and without any maintenance intervention. Such an approach is so highly complex that a compromise procedure combining a strong empirical base and a mechanistic approach is generally adopted to achieve a reliable model. The empirical base includes time-series pavement condition data compiled on pavements exposed to different environmental and loading conditions. With regard to mechanistic principles, interactions between traffic loading and pavement strength parameters, between loading and pavement deflections, and so on are carefully observed and included when significant.

Performance is a broad, general term describing how pavement conditions change or how pavements serve their intended function with accumulating use. What should be included in a performance evaluation depends to a large measure on whether one's interest lies in project-level or network-level activities. Various approaches have been used in quantifying the performance measure. For example, Pavement Condition Rating (PCR), which is a composite statistic derived from functional and structural conditions of pavement, is used as a measure of serviceability.

The task of predicting the responses of pavements to a battery of interrelated variables is a complex problem that can be accomplished only by resorting to a number of assumptions and simplifications with use of computational techniques. Ideally, data collection would consist of complete histories, or sample functions, of say PCR versus time for roads belonging to a particular family of pavements. It would also be convenient for data to be collected from roads put into use at the same time, so that their ages would be identical.

4.6 Pavement Deterioration Models vis-a-vis Computational Techniques

Several performance prediction/deterioration models have been proposed over the years. The models vary greatly in their comprehensiveness, their ability to predict performance with reasonable accuracy, and input data requirement. Most of the models are empirical and were developed for use under particular traffic and climatic conditions. Few of the models are of mechanistic – empirical type in which some of the input parameters can be calculated using mechanistic models.

Pavement Deterioration Models may be categorized into two kinds: deterministic and probabilistic. Deterministic models include primary response, structural performance, functional performance, and damage models. All of these models may be either empirical, implying they are developed from regression analysis, or mechanistic-empirical correlations.

Deterministic modelling techniques are most common because of their relative simplicity, ease of use, and familiarity. These techniques include straight-line extrapolation, S-shaped curves, polynomial constrained least squares, and logistic growth models. However, these models do not take into account the uncertainties in pavement behaviour under variable traffic load and weather conditions. Developing models require an accurate and abundant dataset. Accuracy of datasets can be greatly affected by regular maintenance or minor rehabilitation activities. It is necessary to include all confounding variables that affect pavement deterioration. The critical disadvantage of deterministic models is that they do not take into account the uncertainties. Modelling uncertainty requires the use of probabilistic operation research techniques.

Probabilistic models include Markov Chain (MC) models and survivor curves. Knowing the "before" condition or state of pavement in probabilistic form, one can employ the Markov process

to predict the "after" state, again in probabilistic forms, for as many time steps as are desired. The evolution is governed by a characteristic transition rule, otherwise known as transition probability matrix in MC theory. Survivor curves describe pavement deterioration in the form of a cumulative distribution, which subsequently can be employed to develop a transition probability matrix. The principal advantage of probabilistic predictions lies in their ability to recognize and accommodate uncertainties in design/analysis leading to reliability-based designs.

Application of Probabilistic Pavement Deterioration Model for modelling pavement performance was first discussed in the early 1970's. Among the probabilistic models, the Markov model is generally considered in modelling pavement performance. Many researchers attempted to develop the pavement performance model using the Markov process so as to work as a decision support system for pavement maintenance management. The advantages of using a Markov process in the Pavement Management System (PMS) has been studied by many researchers. A critical component of the Markov model is the Transition Probability Matrix (TPM). Generally, the TPM is calculated based on the historical pavement condition data. Prediction of the pavement condition for the future using the Markov model for the deterioration progression usually starts with developing a Transition Probability Matrix (TPM). A TPM represents the probability that a segment will stay in a specific condition for a specific year. As reported in the literature, some highway agency utilizes three types of deterioration models in their Pavement Management System (PMS): site-specific, family, and expert opinion curves. These curves are developed using deterministic techniques.

Formulation of the Distress Indices is one primary requirement in the pavement deterioration model. The distress indices can be scaled from 0 to 100, where 100 represents a flawless pavement with no distresses and 0 represents the worst condition. The Markov model provides a prediction of pavement performance from the distress index either by each distress index or a combined index representing the overall pavement condition. Most commonly used pavement distress indices are cracking (transverse and longitudinal), rutting, ravelling and roughness. Usually, these indices range from 0 to 100, where 100 represents the best condition and 0 for the worst condition. A pavement section begins its life in a near-perfect condition. Over the years, the pavement condition deteriorates due to many factors such as traffic loading, weather conditions and level of routine maintenance. In order to develop the deterioration models using the Markov process, it is required to collect the distress data continuously for minimum five years including history of preservation/rehabilitation.

4.7 Pavement Condition Assessment

Condition of road pavement can be expressed in either descriptive qualitative terms such as; very good, good, fair, poor and very poor OR condition indices values in quantitative terms ranging from scale 0 to 10/0-100. Although descriptive terms hide some important details, however they are universal and easily communicated to policy makers and to the general public. Such qualitative rating terms namely vey good, good, fair, poor and very poor are typically based on the pavement appearance and/or ride quality at the time of condition survey/ condition rating.

However for effective asset management implementation and its monitoring point of view and when engineering threshold values are prescribed as a measure of pavement performance

during its service life, it is always advisable to express pavement condition in terms of quantitative assessment of condition/distress indices based on a continuous rating scale (i.e., 0 to 10 or 0 to 100). One end of the rating scale defines failed pavement, and the other end defines excellent pavement condition and/or no distress, such as in case of a new pavement. Some global organizations of repute use the rating scale to calculate one distress index for each type of distress (i.e., individual distress indices), while others use a composite pavement index. A composite index is typically based on several types of distress and/or condition. Examples of composite pavement indices include Pavement Condition Index (PCI), Pavement Quality Index (PQI), Pavement Serviceability Index (PSI), Pavement Condition Rating (PCR) , Overall Pavement Index (OPI), and so forth. Along the rating scale, one or more threshold values are typically established to flag pavement sections for possible treatment actions. One threshold value could be based on the need for maintenance, another on the need of preservation action, and a third could be based on rehabilitation. Depending on the functionality of the threshold value (maintenance, preservation, or rehabilitation), a distress index value below the established threshold value indicates the need to maintain, preserve, or rehabilitate the pavement section in question. The rehabilitation threshold value typically separates acceptable from non-acceptable pavement conditions.

Among several methodologies for rating road pavements, the most commonly used composite index is Pavement Condition Index (PCI), which rates the severity and density of specific distresses in pavement over its service life. Once the condition in terms of PCI is known, the remaining service life of the asset can be determined using a graph similar to **Fig. 4** below.

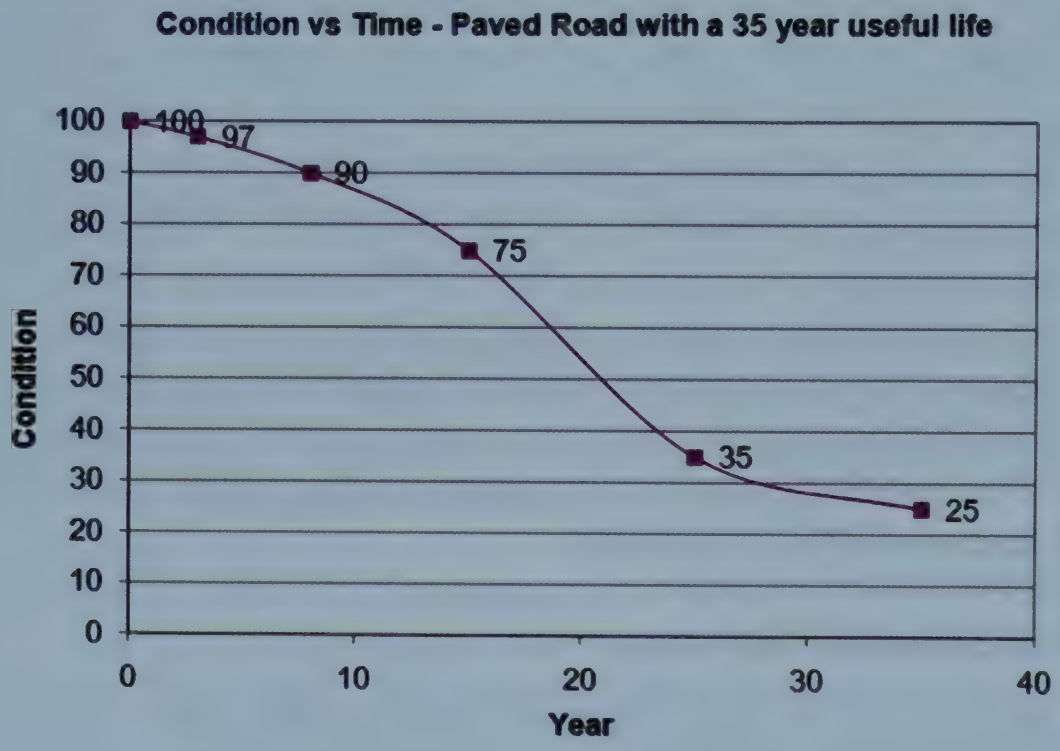

Fig. 4 Pavement Condition Based Service Life Prediction

Using this chart; if a road section with a 35-year useful life has a current PCI condition rating of 80 the road section would be at an estimated age of 12 years. Within 3 years the road section should be at condition rating 75. At this condition rating a renewal strategy, as identified in the asset management plan, would be applied. Likewise, at condition rating 35 in year 25 of the assets to remain useful, a second strategy would be applied and finally the asset replaced at year 35 or condition rating 25.

4.8 Pavement Performance vis-a-vis Pavement Preservation

The performance of a pavement segment is often illustrated by the progression of pavement condition or distress over time, as shown in **Fig. 5**. The level of performance at any given time is equivalent to the level of pavement condition or distress at that time compared with the threshold value. Therefore, the performance of a pavement segment over its service life is defined by the level of service over the time or by the accumulation of damage over time.

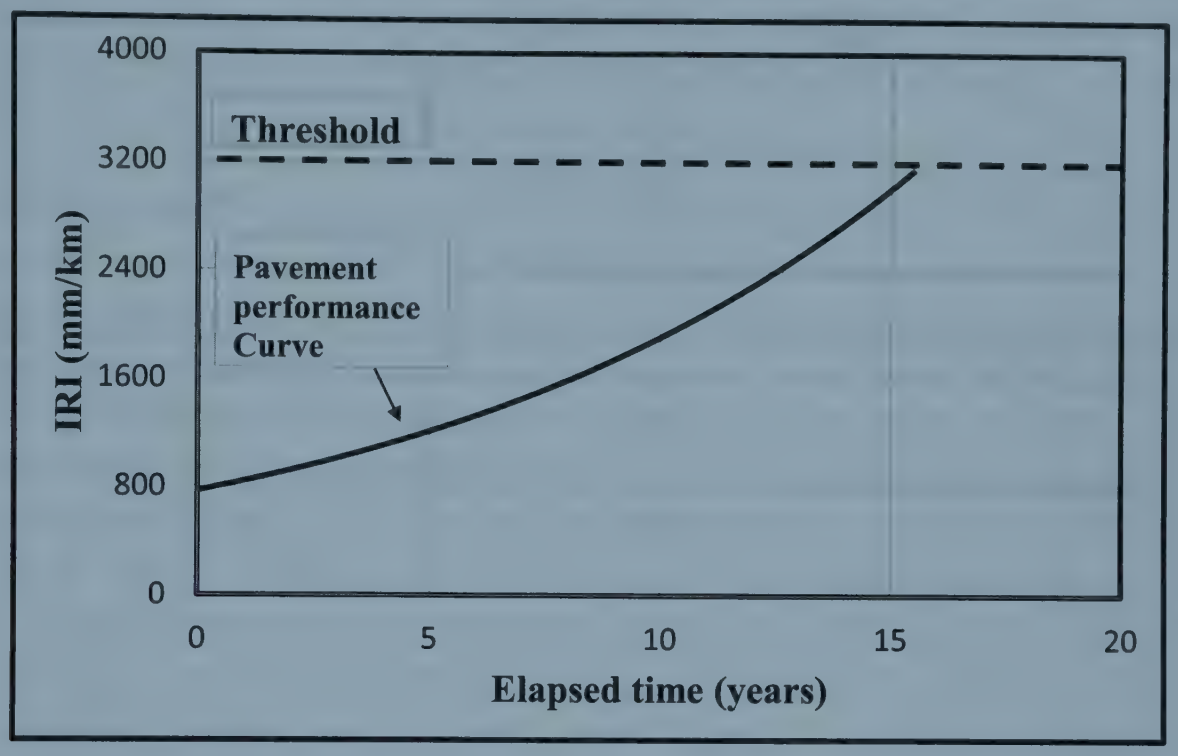

Fig. 5 Typical Pavement Performance Curve with respect to Roughness Value

Most procedures for estimating pavement preservation benefits are based on the prediction of future pavement performance, comparison of the pavement performance before and after treatment, and immediate changes in the pavement conditions resulting from treatment. Although the commonality among all procedures is a prespecified threshold value, the actual value of the threshold varies from one procedure to another. Some procedures set one threshold value for each type of pavement distress and condition, while others use the combined distress index and an overall threshold value. Still others use one threshold value for maintenance, one for preservation, and one for rehabilitation and/or reconstruction. Further, some procedures use the term life to express the benefits. Such a term should not be taken separately from service life. For example, the term pavement design life used as a guide for design of pavement, in reality, expresses the pavement level of services based on engineering threshold values for acceptable riding quality in terms of roughness, rut depth, cracking etc.

4.9 Assessment of Remaining Service Life

A popular concept used in making pavement management decisions is the Remaining Service Life (RSL) concept. This concept is based on the premise that a pavement section has a period of time remaining before the pavement reaches a point at which it is considered to have reached a minimum operating condition as illustrated in **Fig. 6**. When this point is reached, the pavement will typically require major rehabilitation or reconstruction, depending on how the pavement management system is set up. If the RSL of a pavement segment is 10 years, then it is estimated that it has 10 years of use before it reaches the terminal threshold. If the RSL is 0, then the segment has already reached the threshold.

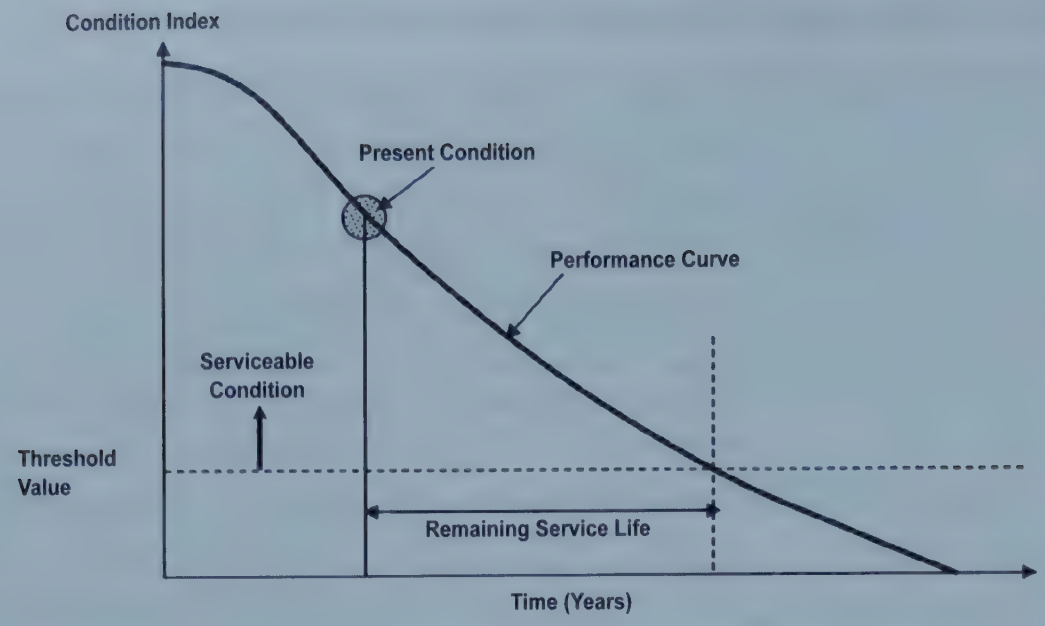

Fig. 6 Conceptual illustration of Remaining Service Life of a Pavement

The RSL concept can be applied in pavement management systems at all levels: project segment level and over the entire network. When considering the segment level, the RSL of an individual roadway segment is determined based on the actual pavement condition or the predicted condition based on deterioration models as illustrated in **Fig. 6**. At the network or branch level, the RSL of the entire system or subsystem is estimated based on the condition of the individual components of the system. In this case, the pavement maintenance manager/ concerned Road Agency's goal is to keep the condition of the overall system or network above a particular threshold level.

When implementing the RSL concept in a Pavement Management System (PMS), the goal is to maintain or improve the overall health of the entire network to an acceptable level of service. The network health in terms of either descriptive (i.e qualitative) or quantitative terms can be evaluated/predicted using standardized procedures. The action taken in programming pavement maintenance and construction planning will have a significant impact on the overall health of a network as every maintenance, rehabilitation, and reconstruction activity will improve the remaining service life of a pavement section to a different degree.

4.10 Pavement Preservation Treatments and Methodologies

It is imperative to clearly understand the methodologies, treatment options and timing of application of any pavement preservation intervention to achieve best results of implementing RAMS by the Organization. There are several pavement preservation treatments that have been used across the Globe with varying degrees of success. Each of the treatments has shown to be both effective and ineffective and the success of the treatment largely depends on the condition of the pavement prior to application of the treatment. In other words, was the correct treatment applied to the road/network of roads in question? Many a times, the answer to this question is no. Therefore, it is of the utmost importance to understand where, when, and how a specific pavement preservation treatment should be applied.

The most effective method for maintaining pavement serviceability is to implement a pavement preservation program which is a planned system of pavement surface treatments designed to extend the life of a pavement. Any pavement preservation program generally

takes in to account three types of basic maintenance activities namely; routine maintenance, preventative maintenance and periodic maintenance with minor or nonstructural rehabilitation components.

Routine maintenance is a corrective procedure that repairs localised distresses, such as cracks and potholes, when they occur. Roads in this category are in generally good condition, but require localised repair to prevent accelerated deterioration. Thus, from the asset management principles, it is a planned programme performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate/desired level of service.

Preventative maintenance techniques for pavement preservation are specifically applied on pavements that are in good condition with a considerably long remaining service life. It is a planned strategy of cost-effective treatments which preserves the existing roadway system and its appurtenances, retards future deterioration, and maintains or improves the functional condition of the system without substantially increasing structurally capacity. However, timing is important to the success of any preventive maintenance treatment, particularly for “surface coat” which serve as a "sacrificial shield' that protects the pavement from the aging effects of the environment and seals out water. Since the main purpose of preventative maintenance is to increase the road's service life by slowing down rate of deterioration due to aging, it is most cost-effective when applied at the first signs of pavement deterioration. This can be identified/ established by adopting a programme approach of pavement condition assessment during the service life while capturing required road condition data through a well defined data collection procedures.

Objectives of minor or nonstructural rehabilitation activities which include restoration treatment and structural overlays are structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation may include increasing pavement thickness to strengthen existing roadways to accommodate existing or future traffic load conditions.

4.11 Timing of Pavement Preservation Treatments

One of the key aspects to pavement preservation is identifying the appropriate time to apply the proper treatment to a given pavement. This is typically the main factor that determines the success of a single treatment as well as a pavement preservation program. Deciding the optimum time to apply a specific treatment to a pavement for preservation purposes has been the subject of only a few studies, but is perhaps the most important factor for a successful pavement preservation program. The impact of timing of a typical treatment is illustrated in **Fig. 7**. The solid line represents the “do-nothing” alternative in which the pavement is constructed and then no action is taken to maintain the roadway. In this scenario, the pavement follows the typical pavement deterioration curve that begins with a gradual decrease in pavement condition for the first 5 to 7 years. After this initial period, however, the rate of deterioration increases rapidly to a point where major rehabilitation is required. Beyond that, complete reconstruction of the roadway is necessary. As the deterioration curve progresses downward, the life-cycle cost of the pavement increases inversely to the deterioration curve.

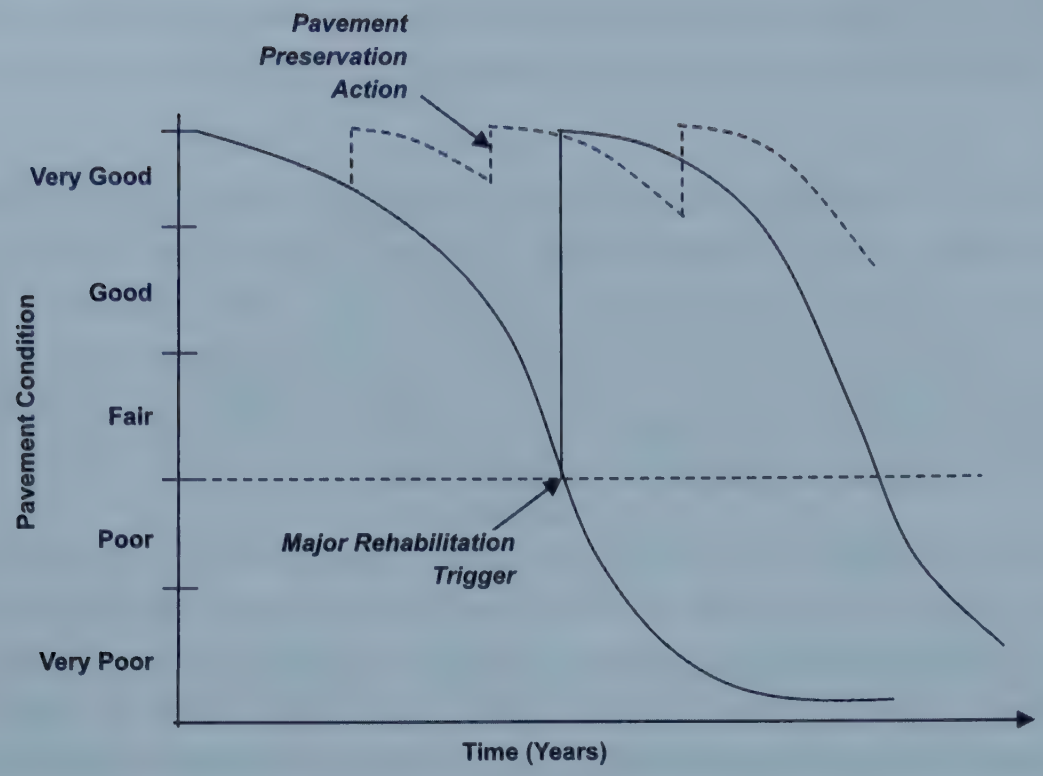

Fig. 7 Conceptual illustration of "do-nothing" and Pavement Preservation Scenarios as per Pavement Deterioration and Remaining Service Life

Fig. 7 also illustrates the concept of pavement preservation where preservation treatments are applied to the roadway at regular intervals throughout the life of the pavement. This is shown with the dashed line. The preservation treatments are applied to the roadway while the pavement is still in good condition after only a minor decline in the deterioration curve. These treatments effectively return the condition of the pavement to near that of when it was first opened to traffic. As the pavement ages, the treatments may become more involved, but the cost of the preservation strategy will always be less than the "do-nothing" alternative over the pavement's life if the right preservation treatments are applied at the right time.

4.12 Establishment of Minimum Standards

A key aspect of asset management is the determination of the performance level at which a standard intervention is to be applied. A profligate policy, where an intervention is applied when the asset is in a state of higher performance, would mean frequent and premature spending of agency funds even though the users derive benefits of perpetually superior asset performance. This would result in negligible incremental benefit and can be considered a waste of agency funds. On the other hand, a parsimonious policy, where an intervention is applied when the asset is in a state of lower performance, leads to the avoidance of agency spending at the cost of severe user consequences of poor asset performance. In between these two extremes, there exists a certain optimal performance threshold for intervention application that is consistent with the maximum possible benefits and minimum possible costs. Given the paucity of analytical research on the explicit and rigorous resolution of this issue, highway agencies have resorted to non-analytical methods such as averaging of historical pre-treatment performance levels or questionnaire survey of various independent domain experts. The best method for establishing a minimum standard of performance for any standard intervention, however, should be systematic, rational, and defensible. For doing this, there exist methodologies that are rooted in simple but robust and widely-known concepts that identify the optimal control decision parameters to yield minimum overall cost at maximum possible benefit or the highest cost-effectiveness.

It is also important to decide whether the minimum standard should be based on aggregate or disaggregate measures of asset performance. The use of aggregate measures seems to be popular with many agencies. In such formulations, maintenance and rehabilitation treatments are carried out any time the aggregate measure falls below a certain threshold or "trigger value". There is no need to carry out field monitoring of each indicator of pavement distresses.

4.12.1 *Pavement Performance Evaluation for Maintenance Intervention*

At each year within the analysis period, assets whose performance just falls below the established minimum standard are flagged for some preservation treatment. The current age is identified on pavement performance curve and thus the year when the asset would reach the minimum threshold limit can be estimated from the curve. Subtracting the current age from the service life provided the remaining service life values or the time frame when the next preservation activity will be due. After the assets that need preservation are identified for each year of the analysis period, this information is synthesized to yield the physical needs: the total length of pavements to be reconstructed, resurfaced, crack sealed, etc.; the number and sizes of bridges to be replaced, have their deck/bearing/expansion joints replaced or rehabilitated, etc.; the number of safety devices to be maintained, etc. A graphical illustration of pavement performance with respect to various maintenance interventions shown in **Fig. 8** explains benefits of pavement preservation considering above implementation modalities.

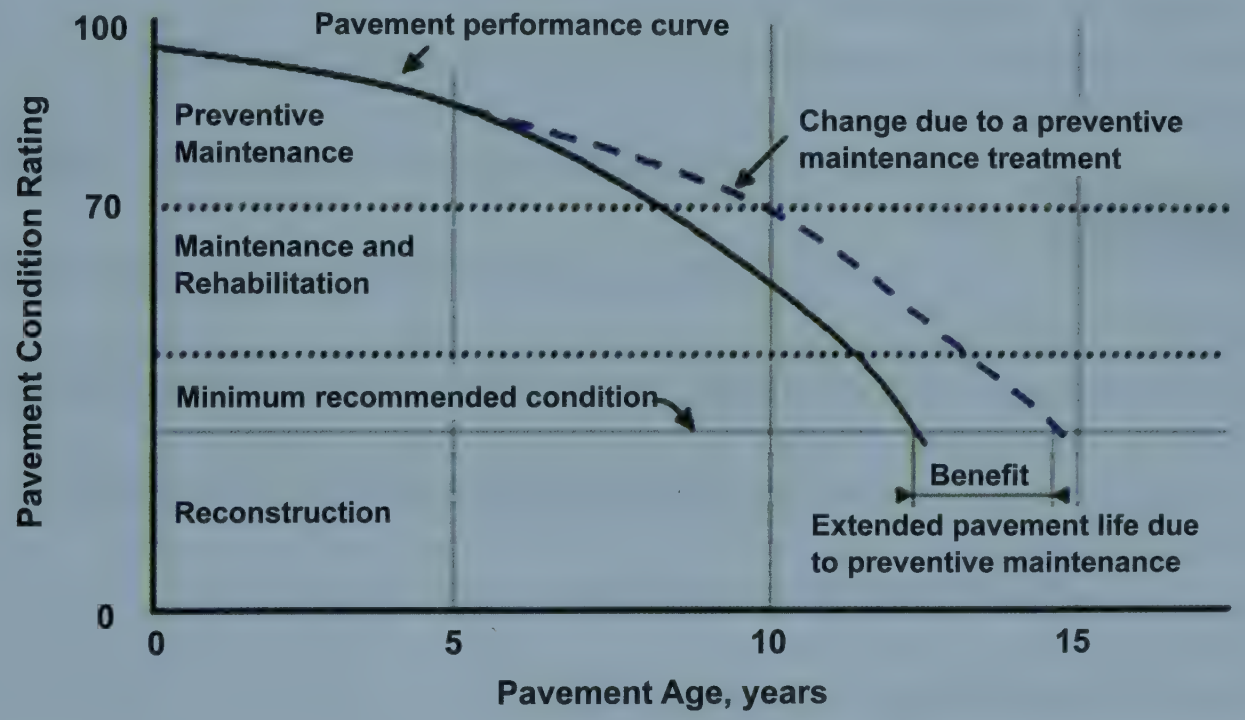

Fig. 8 Pavement Performance with various Maintenance Interventions

4.12.2 *Development of Preservation Treatment Cost Models*

After the physical needs are determined, cost models are developed. Cost models may be for each specific treatment (e.g., Rs/lane-km of microsurfacing treatment) or may be aggregated for each broad category of treatment, for example, Rs per lane-km for general preventive maintenance, reconstruction, or rehabilitation. Cost models, which are key inputs for the monetary needs assessment, can be developed as average values for each category of asset type, material parameter, location, etc. or may be statistical regression models of cost as a function of the preservation treatment attributes (such as road width, new pavement thickness) and physical

characteristics of the asset and/or its environment (such as functional class, age, condition at time of treatment, year of last treatment, location etc). The highway agency need to prepare cost models for various standard treatments for different classes of highway assets in the location.

4.13 Asset Management Plan and Modules

To implement asset management in road sector and to prepare asset management plan for any road agency/Government sector, it is essential to develop and use three basic modules of road asset management such as Pavement Management System (PMS), Bridge Management System (BMS), and Routine Maintenance Management System (RMMS). In addition, one can also include Road Safety Management System (RSMS), Traffic Congestion Management System (TCMS) and the Intermodal Management System (IMS) depending upon the requirement of the Agency's work function. The PMS, BMS, RMMS,TCMS, RSMS etc are oriented towards the physical state of the road/highway assets, as their primary purpose is to create inventory, track, and address the condition of the various components of the road network and assist in establishing cost-effective strategies to sustain an acceptable condition of such facilities. While some states in our country have already developed/implemented application of some of the described modules, some others are in the process of developing these modules **(Fig. 9)**.

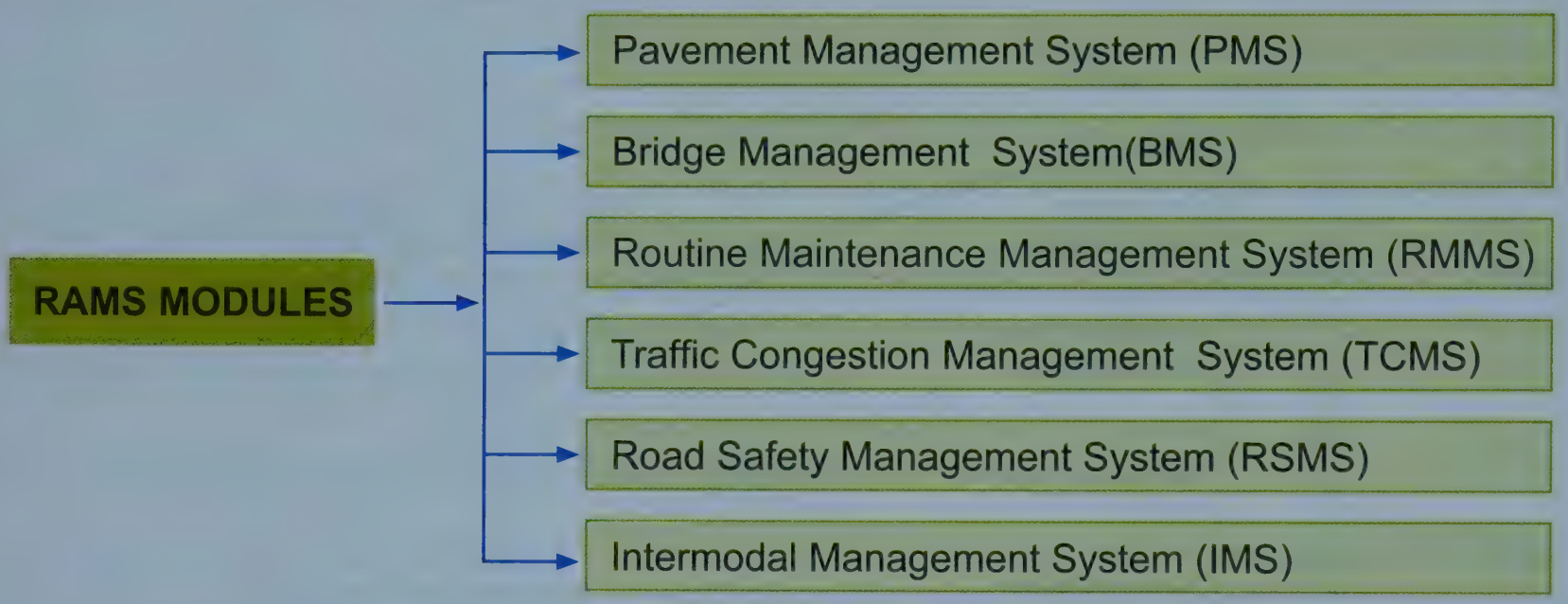
RAMS MODULES
Pavement Management System (PMS)
Bridge Management System(BMS)
Routine Maintenance Management System (RMMS)
Traffic Congestion Management System (TCMS)
Road Safety Management System (RSMS)
Intermodal Management System (IMS)

Fig. 9 Basic Modules of Road Asset Management

4.13.1 *Pavement Management System (PMS)*

In the 1960s and 1970s, some states in USA first began to address the issue of managing pavements by devising methods to show the degree of current pavement deterioration and to prioritize potential improvements according to a "worst first" philosophy, where the pavement in the poorest condition was addressed first. Since then, the concept of Pavement Management Systems (PMS) has evolved as a set of tools that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. Today, the PMSs used by many developed/developing countries and some of our states include all activities involved in planning and programming, design, construction, maintenance, and rehabilitation of the road pavement. This includes the capability to consider both the engineering aspects and the economic aspects of pavement investments and the return on investment.

Use of a PMS approach has been shown to be more efficient than focusing on the "worst first." Principal components of a PMS are data collection and management, analysis and feedback/ updates. The PMS module requires analytical tool such as Highway Development and Management Tool (HDM-4) or similar tool to predict road condition and to suggest treatment option using life-cycle cost. The in-built deterioration modelling of any PMS analytical tool helps in predicting the road condition considering proposed intervention options by extracting the required data stored within the road database of RAMS such as road inventory, composition, pavement inspection data on distresses, roughness, structural strength etc while configuring maintenance strategy, vehicle fleet and economic parameters. The PMS analytical tool determines the road maintenance and improvement requirements for specific roads and for the overall network including budget requirement. The analytical component, at the network-level, prioritizes roads on the basis of cost-effective treatment options and at the project level, it recommends cost-effective repair treatments.

For managing periodic and capital road works activities a Pavement Management System (PMS) application is required which should cover preservation of the existing road network as well as expansion which may cover new links, multi-laning, or capacity increases. The PMS in general should be user-friendly, for simple and direct application. The engineering and economic analytical tool of PMS should include deterioration prediction model for both bituminous and concrete pavement. The processes to be covered must include network-level planning, project-level planning, multi-project programming and budgeting, optimization of projects under budget constraints besides overall network performance monitoring and evaluation against projected targets. Several road authorities/organization in our country have in place, some form of PMS which is an integral part of any Road Asset Management Program.

4.13.2 *Bridge Management System (BMS)*

A Bridge Management System (BMS) is a systematic approach to assist in making decisions regarding cost-effective maintenance, rehabilitation, and replacement plans for bridge structures. Such systems seek to identify current and expected future deficiencies, estimate the backlog of investment requirements, and project future requirements for each bridge in a network. At a network level, a BMS helps to identify the optimal program of bridge investments over time periods, given budgetary allocations. Also, BMS plays an important role in risk management as evidence to counter possible claims alleging negligence for the agency's failure to upgrade a bridge in light of changed conditions and current design standards, can be provided. Typical BMS components include a database, cost and deterioration models, optimization tool for maintenance and improvements, and integrated project programming and updating functions. The database component contains information from regular field bridge inspections. Deterioration models predict the future condition of bridge elements. Agency cost models are associated with maintenance and improvement of bridge components, while user cost models relate more directly to bridge safety and serviceability. Using results from the cost and deterioration modelling, an optimization model determines the least-cost maintenance and improvement strategies for bridge elements.

4.13.3 *Routine Maintenance Management System (RMMS)*

Routine Maintenance Management System (RMMS) is another desired basic module inside RAMS, which determines the on-carriageway and off-carriageway routine maintenance

requirements for sections of a road/highway not receiving periodic maintenance or improvement in a particular year. The RMMS module prepares routine maintenance budget for the routine maintenance activities, which are generally carried out by all the road authorities/organization every year based on maintenance allocation. Using RMMS module, one can assign routine maintenance activities to sections based on pre-defined maintenance matrix as per pavement condition survey data. At least four to five critical condition/distress data of road pavement such as pothole, ravelling, rutting and cracking should be considered to assess on-carriageway routine maintenance requirements. Similarly, two to three condition attributes such as shoulder depression, erosion/raincut and safety features for the off-carriageway maintenance requirements. The programming of RMMS module should be done using pre-defined rule-set procedure as per standard IRC/MORTH maintenance treatment specifications, which shall help the system to automatically assign treatment options based on the condition attributes for determining the routine maintenance budget for a particular year.

4.14 Desired Attributes of Road Asset Management System

The primary function of a Road Asset Management System (RAMS) is to serve as a monitoring and decision making tool for highway agencies. Toward this end, the system must have the following attributes:

4.14.1 *Comprehensiveness*

An asset management system must address a broad range of components, procedures, and outputs.

4.14.2 *Service-driven*

Unlike organizations in the private sector, the highway agencies do not pursue profit maximization as their objective. They would rather provide proper level of service to the road users while sustaining system condition with limited funding. As such, a Road Asset Management System (RAMS) should be service-driven and must hold the perspectives of the road user and community as the primary interest.

4.14.3 *Flexibility*

The management system must be flexible to accommodate variations in different regions of a road network. Such variations include road functional class, unit costs of road activities, priorities among system objectives, preferences over different road functional activities, differences in climatic and environmental condition, and so on. Management system needs also change with time as responsibilities shift, infrastructure elements change, organization and budget compositions are restructured, and new technologies are developed. A management system should therefore be oriented to the type of agency it is intended to serve, and be flexible to change with changing requirements.

4.14.4 *Sensitivity*

To be a good strategic decision-making tool, the Road Asset Management System (RAMS) must be capable of analyzing the impacts of changing macroeconomic factors such as inflation,

changes in vehicle characteristics, and changes in type and intensity of traffic loadings. It should also be capable of analyzing the implications of different highway policy decisions.

4.14.5 *Coordination*

Most state highway agencies currently operate management systems that could provide valuable information for Road Asset Management System (RAMS). These systems are intended to cyclically monitor the condition, measure the real-life performance, predict future trends, and recommend candidate projects and preservation treatments, and monitor the implications of investments (or lack thereof) on systems objectives, such as safety and level of service.

4.14.6 *Long-term Planning*

An asset management system must enable the agency to carry out planning in the long term.

Given the multi-dimensional nature and the multiplicity of elements in each dimension, it is vital that the ideal Road Asset Management System (RAMS) should be a comprehensive and coordinated, yet flexible and sensitive enough that can adjust to changes in the road transportation environment and public perceptions **(Fig. 10)**.

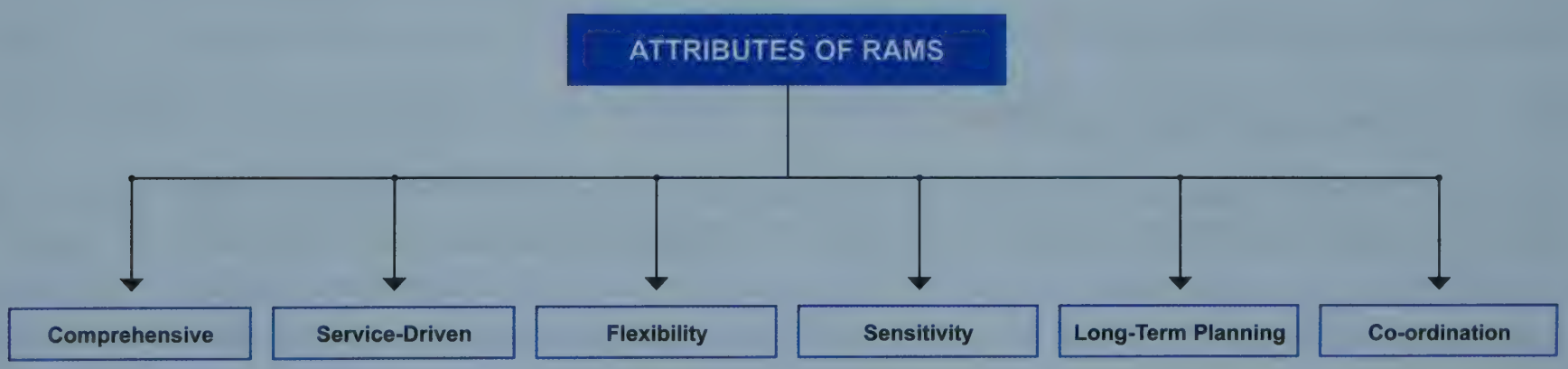

Fig. 10 Attributes of Road Asset Management System

5. ROAD ASSET DATA COLLECTION

5.1 Type of Data Needed

A key objective of RAMS is to provide a factual basis for improving the quality of decision making regarding the budgeting, design programming, construction, maintenance and operation of a pavement network. Quality decision making requires a current inventory of the pavement system, evaluation of the present condition and use of the pavement system, estimation of future condition, and the implications of any changes in condition.The specific type of data needed to make informed Pavement Management Decisions will vary with factors such as the size, complexity and condition of the pavement network, the levels of service to be provided, the agency budget and budgeting process (ASTM:E1777-09 2009).

The data base is a central feature of RAMS in the modern context. The types of data needed for pavement management can be broadly classified as inventory data and pavement condition data. Inventory data describe the relatively permanent features related to the pavement sections and would typically include pavement construction and maintenance records. Pavement condition

data include measures of pavement quality, which are broadly classified as performance/ roughness, structural, distress and safety/skid data (Haas et al. 2015).

Data base acquisition and to maintain a database of historical and current conditions of pavement is necessary for the efficient functioning and quality decision making within RAMS as discussed above.

5.2 Levels of Data Collection

Data collection may be considered as belonging to one of the following three levels:

- **Network-level data** should answer the general planning, programming, and policy decisions supported by the network-level RMS;
- **Project-level data** should support decisions about the best treatment to apply to a selected section of road. As these data are collected, they can be stored to create a more complete database over time. However, a method must be established to keep the data current; and,
- **Research-level data** should be established to collect detailed data on specific attributes to answer selected questions.

Requirements shall be as per the analytical engine to be used.

5.3 Method of Data Collection

The cost of data collection tends to be the largest component of managing and running a RAMS. Further, the direct benefit of frequent (or regular) collection of information is always questioned and is continually subject to budgetary scrutiny. It is therefore important to select data acquisition technology that is appropriate to the objectives, resources and modus operandi of the agency.

The criteria that can guide the selection of the data collection method are:

- Reliability: A trade-off between the accuracy of the method and its productivity.
- Accessibility (Resources): Deals with the efforts required to transfer the data from the collection medium to the database, the capability for reviewing and verifying the data before storage, and the speed and accuracy with which transference to storage can be made;
- Affordability: Includes technical support, staff and financial resources required to sustain the data acquisition process continually through the annual operations of the agency.

The road inventory and pavement condition data collection has improved considerably as a result of development of efficient and accurate equipment for data collection.

These can be summarized as:

- Automated Road Survey System (ARSS) based on Global Positioning System, Pavement Distress Measurement Systems (PDMS) using High Resolution Camera, Laser Crack Measurement System, Right-of-Way Video Imaging System (ROW-VIS) using High Resolution Color Camera or LiDAR, Automatic Rut Measurement

System (ARMS) using Multi–point Laser, Laser Rut Measurement System, Laser Crack Measurement System, LiDAR, Geometry Measurement System (GMS) etc. for capturing road inventory and pavement condition data.

- Laser Profilometer (LP), Fifth Wheel Bump Integrator (FWBI), Automatic Road Unevenness Recorder (ARUR), Car Axle Mounted Bump Integrator (CAMBI), Accelerometer Based (AB) Equipment for roughness measurements (as per IRC:SP:16-2019).
- Laser Based Mean Profile Depth (MPD)/Texture Measurement, British Pendulum Tester (BPT) and Continuous Friction Measuring System (CFMS) for measuring frictional properties of pavement surface.
- Benkelman Beam Deflection (BBD), Falling Weight Deflectometer (FWD), Light Weight Deflectometer (LWD) for measurement of pavement deflection.
- Ground Penetrating Radar (GPR) for determination of pavement layer characteristics.

Similarly, data collection equipment for traffic volume counts and axle-load survey such as Automatic Vehicle Classification (AVC), Static Weigh Scales (SWS) and Weigh-In-Motion (WIM) system are also essential to supplement traffic related data while running any RMS modules for planning and programming purpose.

5.3.1 *Factors for Selection*

The factors that could influence the selection of method include:

- Accuracy of the data;
- Frequency and sampling density of the surveys (use of data in network-level or project-level applications);
- Size of the network to be surveyed;
- Management of data acquisition, whether centralised, decentralised or out-sourced, (and the feasibility for sharing the service with another agency); and
- Technical skills, maintenance support, staff resources and financial resources of the agency.

5.3.2 *Available Methods*

Manual or Semi-automated methods, which are relatively slow, human resource-intensive and require manual data transfer for database, are appropriate when the network is small, the traffic volumes are low and the survey crew costs of conducting the survey are inexpensive. Automated methods, particularly composite instrumentation that measures several items simultaneously, are often fast, consistent, reliable and provide direct data transfer, but they are usually expensive and are thus suited to large or heavily trafficked networks, and to agencies that have maintenance support for sophisticated electronic equipment.

5.3.3 *Inventory of the Pavement Network*

Inventory of the Pavement Network is most important step in the implementation of a pavement management system. The inventory process is the foundation of a PMS, and must be developed with a well-defined plan for the use of each and every data element collected. The inventory

data provides the pavement manager an accounting of the extent of the network, the types of pavements, their geometry, traffic levels, environmental conditions etc. Essentially, it incorporates information on what exists now, plus past information on such items as maintenance and construction performed. The inventory of the network generally refers to the permanent features of the highway. Because a wide variety of data elements are candidates for inclusion, a balance between the levels of details desired and practical cost considerations for collecting and managing the data will usually be required. There are several major classes of inventory data, historical data, traffic data, environmental data etc. to be considered in pavement management, such as :

- Location - Section reference and description
- Geometry - classification and physical features
- Pavement structure - thickness and material types of layers
- Costs - construction, maintenance, rehabilitation and user costs
- Environment - Temperature and Rainfall
- Traffic - Volume and Load

5.3.4 *Pavement Condition Surveys*

Pavement condition surveys are another equally important requirement of PMS, which can be broadly classified into manual methods and automated condition surveys. While manual methods are cumbersome, slow to perform and includes safety risks, automated surveys can be conducted at fairly high speed with greater level of precision. Manual survey also requires well trained surveyors for measurement of distress or defect values. Pavement condition survey methods are briefly depicted in **Fig. 11**.

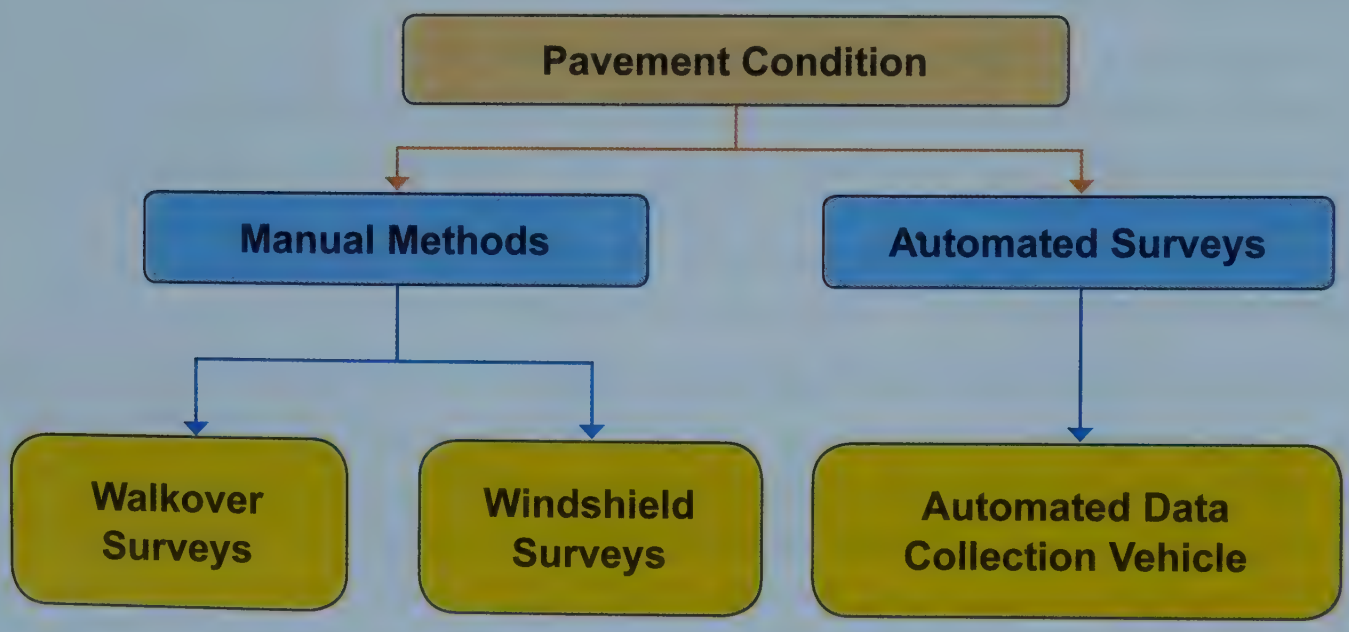

Fig. 11 Methods of Pavement Condition Surveys

5.3.4.1 Walkthrough (Manual) Method

As the name suggests, this method includes recording of the (inventory or condition) data by a team of "pedestrian observers" usually on a sampling basis. Most items are recorded by code indicating the presence, location and attributes of the item.

5.3.4.2 *Windshield Method*

This method includes recording the data from a moving vehicle on a paper or directly into the electronic media (Computer).

5.3.4.3 *Video Logging*

This is very similar to Windshield method that involves recording of data from a moving vehicle. This method is more suitable for recording pavement condition parameters and other visible features. Examples are Network Survey Vehicle and LiDAR technology, which have become popular to record some road related information.

5.3.4.4 *Automated (Equipment) Measurements*

This method involves deploying a combination of electronic and/or mechanical equipment. The equipment will automatically measure the appropriate data with minimal or no manual intervention. The data is recorded in digital form, making it instantly and directly available as soon as the survey is completed. This eliminates the need for data transcription or transfer into electronic format. However, data from this equipment may require further processing or formatting before they are loaded into the database.

5.3.4.5 *Transcription from Records*

This method includes collecting information from other sources, which already have information with them, popularly known as data collection through secondary sources. This involves referring to published or available information, such as detailed engineering drawings, project completion reports, First Information Reports (FIRs), other office records or documents from archives and then transcribing them into digital form for the database.

5.3.5 *Frequency of Data Collection*

The frequency of surveys for monitoring road, bridge, or traffic conditions has an important bearing on the cost of surveys and the sustainability of data collection. Data should be collected only as frequently as is required to ensure proper management of the road network. The frequency can vary depending upon the data of interest. The selection of frequency of data collection is guided by the following factors:

- Level of data collection (Network or Project);
- Intended use of the data (Planning or programming etc);
- Method of data collection (sampling or continuous);
- Significance of the Network (primary, secondary or tertiary road etc);
- Type of funding (public funds or private funds or loan/grant);
- Availability of human resources (In-house or outsourced);
- Compliance with Business plan (support from senior management).

The suggested frequency for various data items is summarised in **Table 5.1** and elaborated in subsections from 5.3.5.1 to 5.3.5.5:

Table 5.1 Frequency of Data Collection

S. No.	Type of Data	Frequency
1	Road Inventory Data	5 years interval
2	Pavement Structural Data	3 to 5 years interval
3	Pavement Functional Data	Every year
4	Pavement Surface Condition data	Every year
5	Traffic Data	Every year

5.3.5.1 *Road Inventory Data* are typically collected as a one-off exercise. They are then updated when changes are made to the road stretch. It is suggested to verify/update the data every five years. Base year information is suggested to be collected using methods given above. It is then suggested to collate information from other sources, such as DPRs, project completion reports, PWD records. The database must be validated through a direct survey at **five year interval**.

5.3.5.2 **Pavement Structural Data** are usually collected at different frequencies, depending on the road class. Pavement strength data are collected in **3 to 5 years interval**. The frequency needs to be sufficient to identify major changes that will influence road maintenance decisions. Pavement composition and history data must be collected through other sources as described above.

5.3.5.3 **Pavement Functional Data** are suggested to be collected at frequent intervals, preferably **each year**. The frequency needs to be sufficient to identify major changes, which will influence road maintenance intervention decisions.

5.3.5.4 **Pavement Surface Condition Data** are suggested to be collected at frequent intervals, preferably **every year**. The frequency needs to be sufficient to identify major changes, which will influence road maintenance intervention decisions.

5.3.5.5 **Traffic Data** are usually collected at designated traffic count stations. It is suggested to collect short-term counts (typically seven days for traffic volumes and one day for axle load) at selected (fixed or varying) locations each year. Accidents information is suggested to be updated every year.

5.4 Criteria for Selecting Data Items

Some road administrations may fall into the trap of collecting large amount of data, but making a limited use of the same for analysis and decision-making. The data acquisition can be expensive but it is needed for implementing and operating a pavement management system. As such, it is essential that appropriate sample size is undertaken, so that the data obtained is relevant, appropriate, reliable and affordable, and cost-effective results are obtained.

The most common problems encountered in the pavement management process are related to data and database operations. The data entered into the PMS must meet certain criteria and need to be entered in the proper format; otherwise the PMS software will fail to give correct results. Therefore, it is essential that appropriate data collection programme is undertaken so

that cost-effective results are obtained. The following are the criteria that should be considered when selecting data items: Relevance, Accuracy, Appropriateness, Affordability, Validity and Security.

- **Relevance -** Every data item collected and stored must have a direct influence on the output required from the system, which should already have been determined. Other data items, which may be considered as desirable, interesting or possibly useful in the future, should be omitted in favour of those that are essential, relevant and of immediate use. Relevance also implies that the data units comply with designated standards, particularly where national or international standards exist.
- **Accuracy -** The values in the database must represent the actual situation at the time the data was collected. This is basically a data collection problem, and the accuracy required must be defined by those responsible for making decisions based on the fund, manpower and equipment constraint.
- **Appropriateness -** The technology and resources involved in acquiring, processing and managing the data should be appropriate to the road administration's capacity for maintaining the equipment, conducting the surveys and sustaining the data processing. The volume of data and the frequency of updating them are major determinants of the cost of operating the management system.
- **Affordability -** The size and quality of all of the data items, and the associated data acquisition, must be affordable in terms of the financial and staff resources available to collect data and keep them current. The scope and quality of data are choices that must be weighed against the resources required to sustain them in the long term, and against the value of the management decisions that rely upon them.
- **Validity -** A given value must be correct. To ensure that the values are correct, the Data Base Management System (DBMS) should include some method to perform edit checks on the data entered. The software should provide a simple method of reviewing data entered and correcting errors.
- **Security -** There are several aspects of security such as data entry, data access, and preventing data loss. Data entry should be restricted to those personnel who have the training, the knowledge, and the need to enter and modify data. Several people may have access to data but proper authorization should be required to enter or modify the data in the database. Even with controls to prevent undesired changes to the data, it can still be lost, damaged or corrupted. To safeguard against this, a backup copy of the database must be stored on a secure place.

5.5 Data for PMS

The following two components have significant role in development of PMS:

- **Location Referencing System**
- **Data Types and Acquisition**

5.5.1 *Location Referencing System*

The entire structure of the pavement management database and all subsequent data collection and analyses are affected by the definition of pavement sections. Therefore, it is important to have a method of defining and location referencing these sections that is workable, consistent

and amenable to updating. The location referencing system used by the pavement management system will significantly impact the utility of the system. There are four basic methods of referencing pavement sections. These are:

- Route-kilometer post
- Node-link
- Branch-section
- Coordinate based system

The Route-kilometer post system is the most commonly used referencing system in highway agencies. In this system, each highway or route is given a unique name and number, which defines the beginning of the segment. The total length of the segment is then divided into equal increments of either ½ km, 1 km or 2 km.

In the Node-link system, key points in the network are defined as nodes and the sections between these nodes are defined as links, which may further be subdivided by fractions of a km.

In highway network, routes or streets may be defined as a branch, and homogeneous sections within the route would be defined as sections.

The coordinate based location referencing system is used in latest GIS/GPS based pavement management systems.

Each of these basic referencing systems has specific advantages and disadvantages associated with its use. However, regardless of the method used to locate data, it must be compatible with the rest of the PMS and analysis systems.

5.5.2 *Data Types and Acquisition*

General types of pavement management data include the actual physical measurement of the pavement, information about usage (i.e.traffic and accident data) and administrative information. Performance related data can be collected either by manual methods of surveys or through automated pavement condition surveys. Various types of data items needed and their acquisition methods are given in **Table 5.2**.

Table 5.2 Pavement Management Data Items and Acquisition Methods

Data Category	**Typical Acquisition Method**
	Performance – Related
Roughness	Subjective rating
	Response type equipment
	Profilograph measurements
Surface Distress	Pavement Distress Surveys (Manual or Automated)
Friction	Continuous Pavement Surface Friction Measuring Equipment
	Pendulum equipment
	Texture measurement methods
Deflection	Benkelman Beam Deflection
	Falling Weight Deflectometer/Light Weight Deflectometer

Data Category	Typical Acquisition Method
Pavement Crust Details	Test Pit (Destructive Method)
	Ground Penetrating Radar (Non-Destructive Method)
History Related	
Maintenance History	Records
Construction History	Records
Traffic and Axle Loads	Records and surveys (Manual and Automatic)
Accidents	Records
Cost-Related	
Construction Costs	Records/Standard Data Book
Maintenance Costs	Records/Standard Data Book
User Costs	Records
Policy Related	
Budget	Records, concerned officials and other agencies
Available alternatives	Records, organizations, suppliers and other agencies
Levels of Service	Public officials and policy statements
Geometry – Related	
Section Dimensions	Records, Estimates, Direct measure and in-situ testing
Horizontal Curvature	Records and direct measure
Cross Slope	Records and direct measure
Vertical Curvature	Records and direct measure
Shoulder/Kerbs	Records and direct measure
Environment – Related	
Drainage	Analysis from record or field observation/measurement
Climate	Analysis from record or field observation/measurement

5.6 Selection of Appropriate Equipment

A user can decide the appropriate method for data collection based on type of the road network. The details are summarised in **Tables 5.3** to **5.6**.

Table 5.3 Performance Related Parameters

Road Category	Roughness	Surface Distress	Rut Depth (mm)	Friction		Deflection	Layer Material Properties
				Texture	Skid Resistance		
Four Lane Divided or More	As per IRC: SP:16-2019 guidelines	PDMS	ARMS	MPD	CFMS	FWD	Laboratory Testing
Two Lane	As per IRC: SP:16-2019 guidelines	PDMS	ARMS	Sand Patch Method	BPT/CFMS	FWD / BBD	Laboratory Testing

Road Category	Roughness	Surface Distress	Rut Depth (mm)	Friction		Deflection	Layer Material Properties
				Texture	Skid Resistance		
Single Lane	As per IRC: SP:16-2019 guidelines	Visual Survey	Manual using 3 m straight edge	Sand Patch Method	BPT	BBD	Laboratory Testing
PDMS: Pavement Distress Measurement Systems; ARMS: Automatic Rut Measurement System; MPD: Mean Profile Depth; CFMS: Continuous Friction Measuring System; FWD: Falling Weight Deflectometer; BPT: British Pendulum Tester; BBD: Benkelman Beam Deflection							

Table 5.4 History Related Parameters

Road Category	Maintenance History	Construction History	Traffic	Axle Load	Accidents
Four Lane Divided or More	Records to be verified with coring or GPR	Records to be verified with coring and GPR	AVC	WIM based Surveys	Records
Two Lane	Records	Records	Manual Survey	SWS based Surveys	Records
Single Lane	Records	Records	Manual Survey	Estimates	Records
GPR: Ground Penetrating Radar; AVC: Automatic Vehicle Classification; WIM: Weigh-In-Motion; SWS: Static Weigh Scales					

Table 5.5 Inventory Related Parameters

Road Category	Section Dimensions	Curvature	Cross Slope	Vertical curvature	Shoulder/ curbs
Four Lane Divided or More	ROW-VIS	GMS	GMS	GMS	ROW-VIS
Two Lane	ROW-VIS or Manual	GMS or Manual	GMS or Manual	GMS or Manual	ROW-VIS or Manual
Single Lane	Records	GMS or Manual	GMS or Manual	GMS or Manual	ROW-VIS or Manual
ROW-VIS: Right-of-Way Video Imaging System; GMS: Geometry Measurement System					

Table 5.6 Environment Related Parameters

Road Category	Drainage
Four Lane Divided or More	Visual Field Observation and Subjective Rating
Two Lane	Visual Field Observation and Subjective Rating
Single Lane	Visual Field Observation and Subjective Rating

5.7 Summary of Some Data Collection Equipment for RMS

A summary of Important Characteristics of Recommended Equipment for Data are given in **Table 5.7**.

Table 5.7 Important Characteristics of Recommended Equipment for Data collection

Name of Equipment	Principle of Operation	Output	Operating Speed	Multiple Measurement	Merits	Limitations	Guidelines
Automatic Road Survey System	Installed with GPS, advanced Laser/ LiDAR, Camera based Sensors	Roughness, Rut, Texture, Distress, Right of Way, Geometry and GPS coordinates	30-100kmph	Road Inventory and Pavement Surface Condition Data	Highly accurate and efficient	Expensive, dry and clean surface measurements	Recommended for Two Lane and Above Carriageway Type
Laser Profilometer	Profile based	International Roughness Index (IRI-m/km) and Texture-Mean Profile Depth (MPD-mm)	30-100 kmph	GPS, IRI and MPD	High Speed Survey	Not Suitable for wet and muddy pavement surface condition	As per IRC: SP:16-2019
Fifth Wheel Bump Integrator / Automated Road Unevenness Recorder	Response type measurement	Roughness Index (RI-mm/km)	32 kmph	NIL	Simple, Reliable data collection	Not Suitable for high speed road corridors (Four Lane and More)	As per IRC: SP:16-2019
Car Axle Mounted Bump Integrator	Response type measurement	Roughness Index (RI-mm/km)	32 kmph	NIL	Simple, Reliable data collection	Not Suitable for high speed road corridors (Four Lane and More)	As per IRC: SP:16-2019

Name of Equipment	Principle of Operation	Output	Operating Speed	Multiple Measurement	Merits	Limitations	Guidelines
Accelerometer Based	Response type measurement	International Roughness Index (IRI-m/km)	Average Survey Speed 50km/hr	GPS and IRI	Portability	Not Suitable for low and high speed traffic conditions	As per IRC: SP:16-2019
Benkelman Beam	Elastic deflection under static load	Rebound deflection at single point under load	Walking Speed	NA	Simple, quick, cheap	Single point deflection	As per IRC:81-1997
Falling Weight Deflectometer	Elastic deflection under impulse load	Deflection basin	NA	GPS and Deflection	Complete deflection profile is measured	Expensive	As per IRC:115-2015
British Pendulum Skid Tester	Measures lateral friction by swing action	Skid resistance	NA	NA	Simple, portable	Noting and recording manual spots measurements only	As per ASTM E303-93 (2019)
Continuous Friction Measuring System	Measures of Skid Resistance	Friction value	Upto 135 kmph	GPS and Friction Value	Requires traffic control	Ineffective in winter, sharp curves and steep grades	As per ICAO Guidelines
Static Weigh Pads	Load measured through load cells/load bars	Static loads	NA	NA	Not suitable for high speed road corridors	Vehicles need to be stopped and aligned	As per standard guidelines set by the manufacturer

Name of Equipment	Principle of Operation	Output	Operating Speed	Multiple Measurement	Merits	Limitations	Guidelines
Weigh-In-Motion	Piezo electric sensors and capacitor type sensor	Weights of moving vehicles	NA	Speed, vehicle type and weight	Traffic is not interrupted during studies	Require special surface conditions for installation with smooth surfaces, steel rimmed tyres should be avoided	As per standard guidelines set by the manufacturer
GPR	Measurement of Thickness of Pavement layers	Pavement Crust Details	Walking Type and Highway Speed Type	GPS and Pavement Crust Thickness	Non Destructive Test	About 90-95% Accuracy in thickness measurements	As per standard guidelines set by the manufacturer
LiDAR	Laser Based geo-referenced point cloud data of road assets	Road assets with its geo-referenced 3D dimensions along with true pictures	Highway Speed	GPS and 3D mapping of Road Assets	Excellent tool for mapping of remote areas	Data Processing Time is Huge	As per standard guidelines set by the manufacturer

Note: Brief details of some Data Collection equipment are given in **Appendix-II**.

6. ASSET DATA MAPPING, ANALYSIS AND INFORMATION MODULES

6.1 GIS Based Asset Description and Mapping

Geographical Information Systems (GIS) should be the basic platform for all spatial features for road assets. GIS based Asset Description allows different physical and operational aspects of a network of highway assets to be modelled as layers that can be edited and manipulated using specialized software. Map outputs and displays are then generated by switching on or off the appropriate layers and assigning to each layer a pre-defined cartographic representation. While other RDBMS store information in tables and provides links between the tables, a GIS goes a step further by providing a geographic component for visualization purposes, an attribute that is particularly relevant and consistent with the spatial nature of transportation system inventories and operations.

6.2 Asset Data Information System

The core of any Asset Management System is Road Information System (RIS) and Bridge Information System (BIS). These are series of databases linking different road and bridge data items. The RIS and BIS should be web based and be accessed either from a centrally linked server or as a distributed database, which is independent of any network. The system should be designed for multi-level user requirements (i.e. Headquarter, Circle, Division, Sub-Division as well as the general public through the internet) with appropriate security, interfaces and reporting facilities appropriate to the level of the user. The GIS based information system for roads and bridges can be developed from the base data of latest Survey of India map and/or satellite imageries of road network. The number of layers and attributed database of the RIS-BIS should be sufficient enough to maintain the inventory and condition diary besides some minimum numbers of critical attributes to determine investment and maintenance/rehabilitation needs. It should have capability to interface with other applications developed by any agency to address various requirements of different management processes.

6.2.1 *Road Information System (RIS)*

The RIS should be web based to ensure operability and data updating using the Internet/Intranet with linkage to data management applications required to meet the needs of the other systems and the management requirements of the respective Govt/Highway agency. It should operate under computer systems and software compatible with the existing systems being used by respective State Government and Government of India with user friendly interface designed around accepted international practices (e.g. common user interface, data import/export standards, truth-in-data standards etc). The RIS must have an inbuilt alert system to ensure updating of road and pavement condition data by every alternate year and flag the year of data collection while analyzing for each parameter. The RIS must have reliable but flexible security system for access and data processing, be capable to check data accuracy, inconsistencies, and the data falling beyond acceptable ranges, be able to export to Excel all the road network data stored on the RIS, being able to export to Excel all the average road attributes for each kilometre of the network and being able to export to Excel all the average road attributes for each homogeneous road section. It should be designed so that the processing time for querying the database and extracting information is satisfactory.

The RIS data model should be capable of handling data of different spatial attributes ranging from point data (e.g. km stones) to continuous or interval data (e.g. roughness) and should handle overlapping sections. The system shall be designed around a proper location referencing system with sufficient flexibility to cater for changes to the system over time. It should also allow for the graphical representation and presentation of information and shall interface with a Geographic Information System (GIS) for mapping purposes.

6.2.2 *Bridge Information System (BIS)*

The BIS should contain cross-drainage and bridge information system databases covering select photographs of CD/bridge structures with sufficient information for any future engineering and economic analysis. The database may contain inventory of all bridges, the results of bridge inspections, and a history of bridge repairs and expenditures, using data available and data to be collected.

6.3 Traffic Information System (TIS)

The module for Traffic Information System linked to the RIS should be capable of storing regular and special traffic counts as well as the outcome from specific studies. The data required to be stored in the TIS module are: continuous counts from permanent traffic count stations, 7/3-day classified traffic counts, short-term (< 3 day) classified traffic counts, traffic growth forecasts, vehicle fleet characteristics, sample hourly flow data, processed weigh-in-motion or axle load survey data (i.e. aggregated statistics as opposed to measurements of each vehicle) and road accidents. Through analysis of this data, the Traffic Information System (TIS) module should be able to produce and report traffic volume and flow characteristics; Average Daily Traffic (ADT), Average Annual Daily Traffic (AADT), seasonal factors, K-Factors, hourly distribution of annual traffic, traffic growth forecasts, predicted traffic patterns of network using supplied traffic growth, vehicle loading characteristics such as average axle loadings and equivalent standard axles, historical and forecast data in a graphical format etc. It shall include, but not be limited to, network utilization, traffic volume and loadings, annual vehicle km of travel, annual tonne km of freight by vehicle class and/or road class besides average accident rates per road or per road class, expressed in number per 100 million vehicle-km (number of total accidents, accidents with fatalities, accidents with injuries and accidents with property damage only).

6.4 Right of Way Features Information Management System (RWFIMS) maintains all features such as structures, utility services both below and above ground, trees etc, within the Right of Way (ROW) and facilitate in generating strip maps showing these features. These database need integration with Road Information System (RIS).

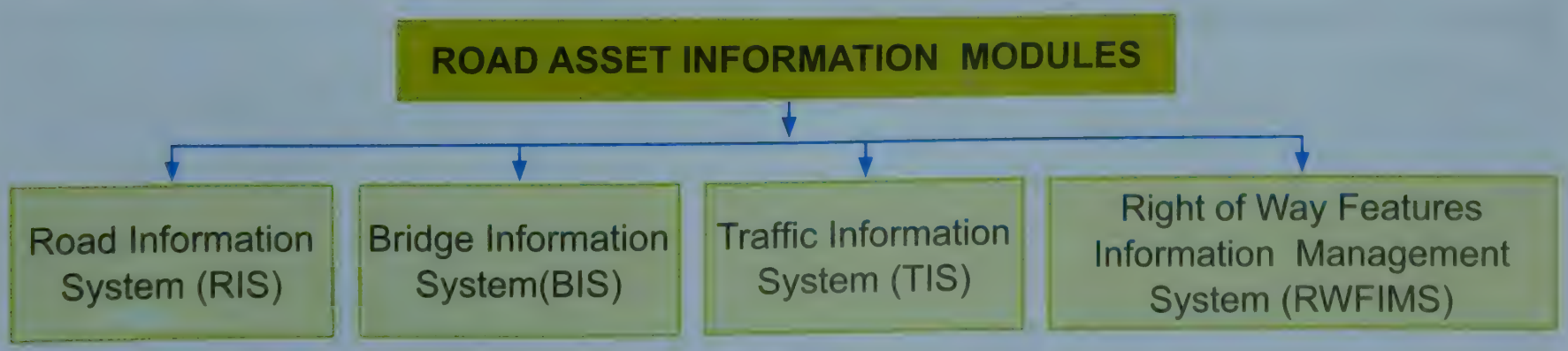
ROAD ASSET INFORMATION MODULES
Road Information System (RIS)
Bridge Information System(BIS)
Traffic Information System (TIS)
Right of Way Features Information Management System (RWFIMS)

Fig. 12 Road Asset Data Information Modules

6.5 Analytical Tools/Numerical Methods/COTS Software

6.5.1 *GIS based tools*

For managing highway asset, data can be classified as those that are GIS-based and those that are not. Typical GIS software packages include TransCAD, ArcInfo, ArcView, and ArcIMS. TransCAD combines GIS and state of the art methods for solving problems in transportation planning, management and operations. It is the first GIS software developed specifically for transportation professionals to store, display, manage and analyze transportation data. The software integrates GIS and transportation modeling capabilities in a single platform. TransCAD can be used for any mode of transportation, at the neighborhood, city, state, national or worldwide scale. The software provides a built-in relational database manager with methods for linking all forms of data, and an assortment of tools for analyzing, interpreting and making effective transportation graphics and presentation using maps. It is a complete application for transportation planning, vehicle routing and distribution logistics. ArcView is a full featured GIS software for visualizing managing, creating and analyzing geographic data. It is the most widely used desktop GIS software as it allows the user to view and analyze the geographic data in an easy way. ArcView can be used for viewing and analyzing spatial data, for building new geographic datasets quickly and easily, to visually model and manage the spatial database, tables, files and other data resources from a single application and to perform calculations with the geographic data and make better decisions. ArcInfo includes all the functionality of ArcView and adds advanced geoprocessing and data conversion capabilities. The software can be used for all aspects of data building, modeling, analysis and map display for screen and output. It can be used to store, edit, display, and plot a simulation network, both before assignment and after. Before a simulation is run, ArcInfo can make maintaining simulation networks easier by maintaining a base network and tracking projects that will change that network over time. By maintaining one network rather than many, problems of network tracking, documentation, and consistency are eliminated. ArcInfo also provides a range of network editing tools and a powerful way to display model results. It is also possible to conduct further analysis of transportation data in ArcInfo using the Network and GRID modules. ArcIMS is a server based GIS application which is used for many types of centrally hosted GIS computing. A centralized GIS application is set-up at the server to provide GIS capabilities to a large number of users over the network. ArcIMS is the solution for delivering and sharing dynamic maps and GIS data and services using the internet. It provides a highly scalable framework for GIS web publishing that meets the needs of corporate intranets and demands of worldwide internet access.

6.5.2 *Planning tools for PMS Application*

These should be established and widely accepted economic evaluation model based on sound engineering and economic priority principles, capable of undertaking both strategic and project level analyses at the appropriate organizational levels, such as the Highway Development and Management Model (HDM-4) or equivalent. The economic evaluation model should have capability in making strategic budgeting studies, project level technical analyses, multi-year road works programming and optimization under budget constraints, and projection of network condition under various budget scenarios covering both road condition and capacity improvements. The

strategic budgeting studies is required to establish necessary funding levels in general budget categories using data of an appropriate Information Quality Level (IQL). The analysis should be based on a life cycle cost approach. The RAMS should be able to establish a medium term budget framework including budget forecasts both for the plan and non-plan budgets; to achieve certain Performance Indicators (PIs). The planning analytic tool is required to conduct the project level analysis for specific sections of road for different technically feasible options such as periodic maintenance, resurfacing, rehabilitation, reconstruction, widening and geometric improvement etc. To allow for preparing optimized multi-year rolling programs, the RAMS must include a multi-year programming module which shall optimize the selection and timing of pavement works under different budget constraints to achieve various performance indicators. The works under these programs would include road widening, reconstruction, rehabilitation, strengthening, resurfacing, bridge rehabilitation/replacement/construction, road safety interventions etc. The works under these plans should be prioritized using rational criteria for investment decisions to maximize the benefits of investment. The optimization shall be done using a heuristic approach such as that adopted for the HDM-4 model or equivalent which contains suitable pavement performance models for predicting the future pavement condition which can be refined over the years. The output for such Multi-year Rolling Plans and Annual Maintenance Plans over short and medium term shall be year-wise optimized work program covering different budget categories and work classes such as periodic renewals, routine maintenance, emergency maintenance, and special repairs. The RAMS user should be able to refine these programs to obtain the most appropriate program given logistical and other considerations. The unconstrained budget requirements for multi-year rolling plans should be prioritized into year wise rolling plans for both road improvement and periodic maintenance considering the budget forecasts from the Government and other sources. The program output should be delivered in a timeframe that meets the Government's budgeting cycle and should have options for revision in an iterative process as more accurate forecasts or actual budget is known. The output of the planning tools i.e the prioritized road sections for the investments in the various plans should be capable of being exported to GIS to be accessible to senior managers of the Government/Highway agency to enable decision making.

6.5.3 *COTS Software*

They are readily available software applications for road asset management which can be on commercial basis. These applications are developed by software vendors who continually develop and upgrade as the new requirements emerge and technology changes. The COTS packages are generally open ended with some standard templates for various modules explained earlier. These templates may be modified for each implementation considering the business processes and requirements of the agency being considered. It is essential to have GIS interfacing embedded in the COTS for easy data visualization and assistance in the decision making process. One can use any of the available COTS software with required customization and configuration as long as it fulfills the requirement of the concerned highway agency or one can develop bespoke application considering the required modules as explained in this guideline. Section 8.3 of the guidelines acknowledges on use of appropriate technology in this regard to make the overall RAMS compatible with the existing IT strategy of any highway agency.

7. ASSET MANAGEMENT DECISION MAKING AND MAINTENANCE PLAN

7.1 Decision Making Criteria

The asset management decisions are generally made at the project level and at the network level. At the management level, the decision-making problem faced by asset managers and the factors that affect the asset manager's decision are mostly dependent on the road policy of the concerned highway agency/government organization besides the institutional issues.

7.1.1 *Network-Level Analysis*

It involves system-wide management functions such as establishing priorities for various projects, determining the optimal use of limited funds, selecting optimum maintenance policies for the entire network and assessing network-level impacts of alternative asset maintenance strategies. The advantage of network level analysis is that it affords the asset managers a birds-eye perspective of the assets under their control, particularly, the performance consequences of different maintenance budgets. A disadvantage is that this level of analysis often utilizes data that are only aggregate in nature and thus does not always consider all factors associated with asset maintenance at the project level.

7.1.2 *Project-Level Analysis*

Project level analysis generally involves the selection and evaluation of maintenance strategies for a specific asset (such as a section of road or bridge). Project-level models are typically comprehensive, dealing with technical concerns and requiring detailed information. Often at the project level, the common task is to select maintenance strategies that will provide an acceptable level of service to the user over a given period of time at a minimum overall cost. Project-level analysis often occurs at each individual component management system.

7.1.3 *Decisions Making Options*

The decision making options can be influenced by either single criterion or multi criterion Network Level Optimisation along with budget consideration. In many situations, network level optimisation can be undertaken on a single criterion (often economic) parameter. When more than one criterion is used to define the optimum solution the single criterion optimisation may be inappropriate and Multiple Criteria Optimisation (MCO) should be considered.

7.1.4 *Budget Considerations*

Whilst the asset management approach advocates the identification of needs, these must often be tampered by the reality of the available budget. Often management decision must be taken within the context of limited budget availability.

7.2 Project Level Decision Making

Here, the asset manager seeks to answer the question "for a specific individual asset, what's the best maintenance treatment to be done at any given time?" For a single performance measure such as life cycle cost or service life, the answer is relatively straightforward. For

several performance measures, however, the decision problem can be structured and solved using multiple criteria techniques. The asset manager thus makes a decision on the basis of the following: asset current condition or/and current age, time-trend in asset condition, current or expected future levels of usage or climatic effects, expected effectiveness of each treatment (increase in condition, treatment life, extension in asset life), cost of the treatment (agency or user or both).

Decision mechanisms to select the best asset maintenance treatment at a given time or strategy over the remaining life, are useful for asset management because they can provide an indication of when a treatment is needed for each asset on the highway system. As such, these decision mechanisms are also useful for life cycle cost analysis and also for long-term needs assessment studies.

The mechanism of the decision is typically in the form of decision trees or decision matrices. To establish this basis, one has to be guided by expert opinion, historical data and practices (average values or models), or rational analysis of both benefit and cost performance measures through mathematical optimization.

Most highway agencies have developed decision support tools for selecting appropriate maintenance or rehabilitation treatments at any given point in the life of a highway asset, mostly for their pavement assets. While most of these tools were developed primarily for rehabilitation treatments, an increasing number of states are now including maintenance treatments of a preventive nature, particularly as data on the cost and effectiveness of preventive treatments become increasingly available. Decision trees (also sometimes presented in tabular or matrix form) have typically been used for prescribing appropriate maintenance or rehabilitation treatment to address a given state of pavement deterioration or a given state or age of the asset. Such decision tools are typically characterized by a set of sequential logical rules and criteria, and are largely based on past experience and expert opinions of pavement scientists and engineers. Typically, such tools include the criteria such as asset material and design type, asset age or/and condition, functional class of highway on which the asset is located, and level of asset usage.

As any strategy consists of one or more treatments, the total cost of constituent treatments can be calculated for that strategy. Also, each treatment in the strategy is associated with a jump in performance (which can also be translated as a reduction in the rate of deterioration) and it is therefore possible to determine the benefit of each strategy as an area under the curve, extension of service life or a reduction in vehicle operating costs. For each strategy, the overall cost-effectiveness can be estimated over the asset life and the optimal maintenance strategy can be identified for each specific asset type.

7.3 Network Level Decision Making

At the network level, decisions to be made include: which asset deserve some maintenance action; for those that deserve some maintenance action, what is the best maintenance action to be done and when (which year) to undertake the action. The answers to these questions involve a yes/no formulation and thus the decision variable is discrete (often, binary). Another problem context is to decide how much to spend every year to preserve the entire network of assets, in which case the decision variable is continuous. The basic matrix for asset project selection at the network level can be prepared based on accepted strategy. The question that arises is on

what basis are these decisions taken. The basis includes expert opinion, historical data and practices (such as raw averages or statistical/econometric models, and rational cost-benefit analysis including mathematical optimization.

7.4 Asset Maintenance Planning

Road asset "maintenance" refers to the set of activities that ensure that an asset remains in satisfactory condition. Several different maintenance terminology such as routine maintenance, periodic maintenance and major maintenance besides frequency/time interval of maintenance intervention exist in our country. Asset Maintenance Treatment generally is a specific maintenance, rehabilitation or reconstruction (replacement) activity applied at a given time. Individual road authorities/Government organization have established, for each asset type, a standard set of treatments to be applied to the asset at a certain age or condition.

7.4.1 *Asset Maintenance Strategy and Life Cycle Planning*

An asset maintenance "strategy" is a combination of maintenance activities applied at various times within pavement rehabilitation life-cycle. This could be over the entire asset reconstruction life cycle (from construction to reconstruction); over the rehabilitation life cycle (the interval between successive rehabilitation treatments); or over the remaining life of an existing asset. An asset maintenance strategy can be based on asset age or asset condition, or both. Synonyms include schedule or set of actions.

Asset maintenance strategies typically consist of treatments of a preventive (proactive) nature, such as crack sealing and thin overlays for pavements. Such preventive treatments are applied before the onset of significant structural deterioration. In some studies, corrective (reactive) maintenance treatments have generally been excluded from strategy formulations because it has been argued that unlike preventive maintenance, they are typically carried out not in anticipation of distress, but to address distress that have already occurred and therefore cannot be included in a strategy unless the occurrence of structural distress types can be reliably predicted.

7.4.2 *Asset Rehabilitation Life-Cycle*

Also referred to as rehabilitation interval, this refers to the period between (a) asset construction and subsequent rehabilitation, (b) two consecutive asset rehabilitations, or (c) asset rehabilitation and subsequent reconstruction. For a given asset type, the rehabilitation life-cycle could be long or short depending on agency policy, traffic loading, climatic condition, funding availability, etc. Often, asset managers seek to update agency policy on rehabilitation intervals by establishing the optimal intervals for a given asset type, traffic loading, and climatic conditions. However, implementation of such prescribed intervals may be associated with more frequent rehabilitation compared to existing practice and thus greater funding needs than current agency budgets can support.

7.4.3 *Asset Rehabilitation Schedule*

An asset's rehabilitation strategy is defined as a combination of high-level maintenance treatments applied at various times within asset replacement life cycle. A schematic illustration of an asset rehabilitation strategy is provided below in **Fig. 13**. Rehabilitation treatments are shown as thick

vertical lines. For pavement assets for example, rehabilitation may include a structural overlay, a concrete overlay, or concrete pavement restoration.

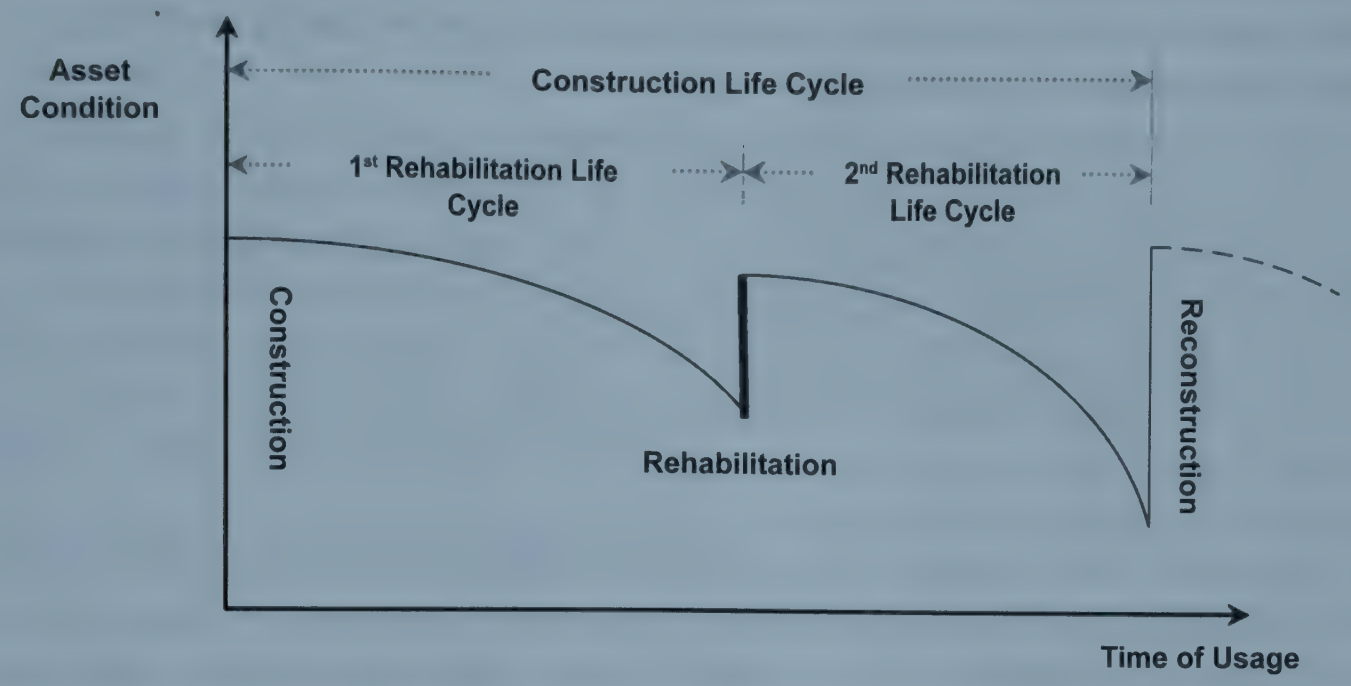

Fig. 13 Road Pavement Asset Rehabilitation During Life-Cycle

7.4.4 *Asset Replacement Life or Life Expectancy*

Replacement life is defined as the period between two consecutive reconstruction activities. In some literature, this is referred to as life expectancy. The literature provides some typical values of life expectancies of highway assets. Highway assets deteriorate with age due to the accumulated effects of usage/loading, weather, environmental exposures and other factors. In order to properly plan and program maintenance and replacement activities, it is essential that the highway asset manager acquires a good understanding of the behaviour of each asset type in terms of its deterioration pattern and consequently, its life expectancy. For most purposes, asset life expectancy can be defined as "the length of time until the asset must be retired, replaced, or removed from service." Updated values of the life expectancy of assets due to new designs, materials, operating conditions, or maintenance programs can help agencies assess the feasibility of extending the time intervals between asset replacements.

8. IMPLEMENTATION, MONITORING AND EVALUATION

8.1 Asset Management Implementation

The implementation and operationalization of RAMS primarily involves:

i) Collection of physical data on inventory and condition of assets (for both roads and bridges) including traffic details using automated equipment based technology, either every year or alternate year depending upon category/importance of the road as per defined process/policy/procedures of the organization,

ii) Development/commissioning of appropriate numerical tool/package/system for analysis of the condition and traffic data using concept of deterioration modelling,

iii) Analysis of various alternatives for maintenance/improvement optimization as per the maintenance/upgradation strategy/policy of the organization,

iv) Preparation of annual work programme with prioritization for implementation on ground considering financial budget availability, and

v) Dissemination of useful information in public domain using web based application with appropriate IT technology.

While looking in to above five primary activities of RAMS, it can be well understood that defined policy/procedures/strategy of the organization, use of appropriate equipment based technology for collection of reliable and useful field data, use of appropriate numerical tool for analysis of data and more importantly availability of exclusive qualified/trained personnel within the organization are some of the key requirements for successful implementation and sustainability of asset management. A dedicated cell/wing with trained/qualified personnel within the organization conversant with field data of pavement distress, data validation, calibration, verification and data management is a prime requirement for the above. Similarly, another team of dedicated personnel conversant with computer application of RAMS, road deterioration modelling, GIS application and web related issues is required for performing activities for entry of collected data in to the developed system and its analysis using developed system software (RAMS), preparation of annual maintenance strategy/plan/report for each road (category wise) under each division/circle/defined jurisdiction within the organization and finally clubbing for entire organization, budget planning and fund allocation considering different schemes/sources of fund on the basis of output generated from RAMS. Therefore, it can be concluded that processes, people and technology are the three critical factors for successful implementation of Road Asset Management. The introduction of RAMS in any organization by itself is not a guarantee that it will be used, or that it will be successful unless there is involvement of and acceptance by senior level engineers/decision makers during the implementation of the system. Development of RAMS by some agencies without clearly defining how it is to be used and who will use it within the agency/department has been reported in some case study reviews. In several instances, it has been observed that the development of RAMS has been done under the assumption that it would find its position within the institution when completed and introduced to the senior management. Therefore, role of the RAMS must be clear from the onset so that its successful use can be made by the organization/highway agency during operationilzation.

8.2 Institutionalization of RAMS

For sustainability of Road Asset Management within an organization/agency's work culture, it is important that institutional support is available from high ranking decision-makers who are fully committed to the asset management/asset preservation 'philosophy'. A separate organizational unit within the department/agencies staffing structure is essential with explicit responsibility for the RAMS, which must be staffed with well-qualified and trained personnel. The development/commissioning, implementation, and operationalization of RAMS (including all computer systems, data, policies and procedures) should be driven by a dedicated group within the department/agency, preferably in the planning division or equivalent. This dedicated group should actively seek to promote the system within the agency, especially to higher level management, raise awareness of the system, manage data collection, constantly look for ways of improving data collection procedures and data quality assurance, periodical review of off-the-shelf RAMS packages available and used worldwide, create and maintain technical and functional requirements for planning and programming systems, and coordinate all efforts related to the RAMS in terms of other applications.

Apart from the key process of asset management, a number of other processes would contribute, including budgeting, financial management, human resource management, and IT management. These processes would be essential in ensuring sustainability of the RAMS in terms of data collection, staff training and development, hardware and software maintenance etc. There should be a budget for the operation of the system, including all staffing, equipment, data collection (outsourced or in-house), field travel, quality assurance etc. There should be a continual training and development program (and budget) for staff to deal with staff turnover and re-training where necessary. Strong contract administration management skills are necessary especially for highway agencies that outsource any data collection. The agency should follow good basic management principles, covering procedures, records, auditing etc. There should be a commitment to continual quality improvement.

8.3 Adoption of Appropriate Technology

As far as technology is concerned, in the present web based computerized environment, it is important that the RAMS implementation should fit within the overall IT strategy of the department/highway agency, and should be properly supported from an IT perspective. It should not be implemented in isolation from the agency's IT strategy. Highway agencies/department may consider outsourcing/external hosting of their systems where possible, given their local environment and according to their overall organizational policies. Any sizeable organization procuring IT should have a Technology Architecture, or explicit technology standards and directions. This is important to avoid a profusion of different infrastructure software (operating systems, databases, GIS etc.) with all the attendant support issues. It is also important in helping to define a replacement/upgrade strategy for hardware and software. There are also distinct economies of scale that can be achieved through centralized procurement of hardware and system software. All IT implementations should preferably use Commercial Off-The-Shelf (COTS) products, wherever possible as custom developed applications have often proved difficult and expensive to sustain. The potential advantages of COTS over developing bespoke software (either in-house or through consultancy projects) is that COTS packages are usually much cheaper to buy than to develop from scratch, the client is not tied to one particular consultant since many suppliers may offer implementation support for the application, the timeframe of implementation is small as COTS package can be quickly used, experience from other organizations/agencies who have used such similar package for a number of years can provide useful information about users adaptability through quick in-house testing, COTS often provides more useful functionality than the client's requirement. Besides it provides scope for ongoing development and up-gradation. The potential disadvantages of COTS are mainly on requirements as the functionality may not be exactly what is required by any agency and therefore some workarounds may be needed. Similarly, during customization, the time to implement new ideas in the software may take longer, since the software vendor/supplier has a responsibility to other clients also. As regards up-gradation, the timing of upgrades is controlled by the software developer, and agencies are often compelled to follow this schedule to ensure future system maintenance. For any future implementation of RAMS, a set of functional and technical requirements should be drawn up. Functional requirements should include the functions that the software should perform. From the wealth of experience available, it is relatively easy to determine generic functional requirements of RAMS to suit the requirement of the organization/road agency. Technical requirements should describe the technology environment within which the RAMS will fit (i.e. hardware,

operating systems, databases, GIS, and other applications). This should relate to the agency's/ organization's Technology Architecture. Agencies should develop and adhere to a long-term IT budget strategy that includes costs of hardware and software maintenance agreements (in addition to hardware replacement strategies).

It must be acknowledged that RAMS like any other system is not static as technology continues to move forward in a number of areas such as IT, data collection, road deterioration modeling, maintenance treatments etc. It is observed that many successful agencies are always looking towards room for refinement and improvement in data collection procedures, quality assurance, road deterioration modeling etc. Therefore, it is essential that dedicated staff looking after RAMS in an organization must keep themselves abreast of developments and look for opportunities to improve the system and its uptake. Organizational planning and budgeting should take this into account, and agencies should be aware of the long-term impact of implementing RAMS. It can be concluded that for development/implementation of RAMS to be fruitful, there is need for continuous support of dedicated people, defined procedures/processes and time tested technology.

8.4 Data Collection Modalities and Contract Management

Implementation of RAMS primarily depends on reliable data. The RAMS will not succeed without reliable data. It is therefore important that data collection equipment and approaches be tailored to the capacity of the road agency/organization. The required data (i.e. inventory, condition, traffic, environmental, and cost data) is vital for successful operationalization of developed RAMS. However, it is observed that collection of data in a scientific manner is also expensive. Each data item requires time, effort, and money to collect, store, retrieve, and use. Therefore, only the key data that are required for use in decision-making process should be collected and stored in the RAMS. These data should be collected at the minimum level of detail with the most appropriate data collection technology given the constraints and capabilities of the organization/ agency. Wherever possible, data collection should be outsourced. It has been reported in various case studies that in many instances the RAMS could not be sustainable due to collection efforts for too much of data in high level of detail. Data collection policies and procedures need to be formalized and should be readily available. If the agency has concerns about operation and maintenance of specialist data equipment in-house, then consideration should be given for outsourcing the data collection surveys. However, it must be recognized that for outsourcing to succeed, there needs to be strong management and quality assurance policies and procedures. Training of agency staff to administer and manage outsourced contracts must be provided in this regard. Strict data quality assurance procedures should be adhered to so that all system users have confidence in the data and analyses provided to them.

In case of outsourcing option for data collection, it is important to have some basic data collection contract management framework. It is required that validation of data for at least 100 km of the network be done prior to the full survey. This will help the vendor/contractor to sort out logistical and technical issues early on and before the full survey commences. This validation survey data should be completely processed and imported to the RAMS where it is verified as suitable. This will (i) confirm that the data processing steps are in place to use the data, and, (ii) ensure that the client/authority can review the submitted data on a timely basis. It must be ensured that every data collection team of the vendor/contractor must perform the validation survey, in case

multiple number of equipment/team are used for the survey. If there are different teams, different vehicles, and different equipment, then all should be tested. The vendor/contractor must produce their own Quality Assurance Plan prior to the start of the survey. This should be approved by the client/authority. Documentary evidence of calibration prior to, and during, the surveys should be mandatory. Considering the dynamic nature of the data, it must be ensured that required data be submitted within a short time period after collection (less than 2 weeks if possible, and certainly not more than 1 month).

8.5 Performance Monitoring and Evaluation

It is desirable to have a process for monitoring and evaluating the asset management implementation by the highway agency/organization through performance measure parameters. Specific and realistic key performance indicators and targets to measure the asset value and to preserve/enhance that value must be periodically done and be explained to the higher management. Some of the key indicators/targets need to be monitored to assess at the end of each year whether they have been achieved or not to facilitate taking appropriate action. Maintenance plan and policies including achievements in a particular financial year need to be published in Annual Reports of the agency. There should be defined policies and procedures in place for data collection, and for quality assurance of the data. Technical (internal and/or external) auditing must be carried out on data and systems, and the recommendations acted on.

There are a number of different ways of carrying out performance measurement. Some of the most commonly used are Random Auditing, where audits can include customer satisfaction, surveys, sample condition surveys, and ad hoc inspections. Random audits are frequently used to independently audit the performance of Highway Authorities who are working under quality management systems. Their purpose therefore is to provide an independent crosscheck on performance.

Similarly one can have System Audits, where asset management software systems have been implemented and if properly used, will provide a source of performance management data. For example customer query systems will be able to provide response times to queries and also be able to identify areas of exception. i.e. particular types of complaint or query or particular geographical areas generating a high number of queries. Where established management systems are in place, it is possible to obtain monthly performance statistics. In general these may focus on activities and the time taken to complete them. Progress against an established programme may also provide a useful management tool. Similarly, some indicators will be based upon information supplied by others annually. This limits the use of such indicators to annual reviews.

8.6 Performance Measures

The key steps in defining highway network performance measures is to first identify the objective. Many highway organizations have published vision, mission and goal statements, as well as objectives. In these instances, the objectives form a logical starting point for the development of performance measures and specifically to identify what aspect of performance is being measured. Sometimes, objectives are often grouped. For example, into areas such as safety, availability, customer service, asset preservation and environmental. This is the approach recommended, by grouping proposed performance measures to support levels of service. The levels of service

from either individual performance measure or when grouped together considering safety aspects of the asset (for example percentage of killed and seriously injured accidents in which asset condition is reported as a contributing factor), condition of the asset (percentage of potholes repaired within 24 hours of alert), availability/accessibility of the asset, environmental impact of the asset, comparison of funding figures/historical expenditure, plan funding, service improvements and innovation, asset growth etc. helps to develop an understanding of how the system of service delivery is (or isn't) supporting progress toward achieving established strategic goals while operationalizing RAMS within an organization. Therefore, the important consideration in starting, by identifying the objective first, is to establish that the elements of the service being measured genuinely contribute to the delivery of a strategic goal.

8.7 Key Performance Indicators

In generic terms of implementing the principles of asset management, any highway agency/ organization adopts options/alternatives available within Road Routine Maintenance Management System (RRMS) or the life cycle option of Pavement Management System (PMS) for multi year plan programme. While doing so, the agency/organization generally carry out in someway or other three activities i.e. i) Routine and Reactive Repair, where the strategy is for routine repair of defects by deployment of available resources on emergency and other non-emergency repairs, ii) Planned Maintenance Preventative action, where the strategy is for upgrading elements to prevent deterioration and iii) Planned Maintenance Corrective action where strategy would be structure replacement/strengthening works involving programme approach as per defined priorities based on overall budgetary allocation. Thus, some of the Key Performance Indicators (KPI) can be derived from above three activities by which the organization/highway agency can monitor and evaluate performance of Road Asset Management System. For example, the average condition of the network in terms of Pavement Condition Indices (PCI) values before and after implementation of RAMS, Percentage of road network above a threshold values of Roughness Index (IRI) as an indication of timely intervention for improvement in riding quality, Percentage of distress in a road network above a threshold values of Potholes/Rut Depth/Cracking/Ravelling or combination of these, number of km of pavements maintained per year, increase in road maintenance funding, multi-year plan works/programme, current replacement cost and depreciated replacement cost etc. provide the basis for many of the KPIs.

8.8 Capacity Building and Training of Stakeholders

There are no fixed set of rules to define and implement Road Asset Management. Each agency is unique in terms of geographical situations, construction and management of its road network, availability of materials, financial and human resources, etc. Therefore, the respective agency must assess and realise its potential, constraints and processes specific to their circumstances. To achieve the best outcomes from the whole process of road asset management, the relevant stakeholders including the senior management must be exposed to the best practices internally within India and also overseas. Capacity building and training must be recognised as important as any other implementation task explained above.

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Appendix-II
(Para 5.7)

BRIEF DETAILS OF SOME DATA COLLECTION EQUIPMENT

1. Automated Road Survey System (ARSS)/Network Survey Vehicle (NSV)

ARSS/NSV is equipped with the following major equipment:

- Distance Measuring Instrument (DMI)
- Global Positioning System (GPS)-Real Time Differential Global Positioning System are used to capture longitude, latitude and altitude of the road assets.
- Roughness using Laser Profilometer (LP)-Two laser sensors installed at both ends of Laser Profilometer are used to collect road profile along left and right wheel paths of the road for the computation of Left IRI and Right IRI (IRI-International Roughness Index).
- Mean Profile Depth (MPD) using Laser Profilometer (LP)-High frequency laser sensors installed in Laser Profilometer are used to collect Mean Profile Depth (MPD) data for the assessment of pavement surface macro texture.
- Pavement Distress Measurement System (PDMS)-Survey systems installed with High Resolution Cameras; Laser based Crack Measurement System, LiDAR etc., provides automated collection of pavement surface images for quantification of pavement surface distresses.
- Road Inventory using Right-of-Way Video Imaging System (ROW-VIS)-Survey systems installed with one or more high resolution color cameras are used to collect right-of-way information.
- Rut measurement using Automatic Rut Measurement System (ARMS)-Survey systems installed with Multi–Point Laser Sensors, Laser spectrum based Rut Measurement System, Laser based Crack Measurement System, LiDAR etc. are used for measurement of rut depth.
- Geometry details using Geometry Measurement System (GMS)-These systems are equipped with inertial sensors such as inclinometer, gyroscope etc. to measure the geometric details of the road network.

Various parameters recorded by ARSS/NSV are presented in **Table A.2.1** and a schematic illustration of ARSS is given in **Fig. A.2.1**.

Table A.2.1 Parameters recorded by ARSS/NSV

Parameter Recorded	Equipment/Technologies
Distance Measurement	Distance Measurement Instrument (DMI) connected to the wheel axle to provide distance and velocity information.
Geographical Position and Geo Referencing	GPS equipped with the vehicle is capable of recording location coordinates of vehicle as well as geo reference important structures like bridges, culverts, railway crossings etc.

Parameter Recorded	Equipment/Technologies
Roughness and Texture	Roughness is measured in terms of IRI, from the longitudinal profile of the road generated with help of Class-1 Laser Profilometer and Texture as Mean Profile Depth (MPD)
Pavement Surface Distress	Pavement Distress Measurement System (PDMS) using High Resolution Camera, Laser Crack Measurement System, LiDAR etc.,
Road Inventory	Right-of-Way Video Imaging System (ROW-VIS) using High Resolution Color Camera or LiDAR
Rut Measurement	Automatic Rut Measurement System (ARMS) using Multi–point Laser, Laser Rut Measurement System, Laser Crack Measurement System, LiDAR
Geometric Details	Geometric details like gradient, rise and fall, cross slope and horizontal curvature are measured with Geometry Measurement System (GMS), which is normally based on accelerometer and gyroscope sensors.

Fig. A.2.1 A Typical View of NSV

2. Laser Profilometer (LP)

Laser based road profiling is a high-speed road roughness measuring system as per ASTM E950 (Class-1 category). The Laser Profilometer beam is installed in the front or back of the survey vehicle. This system is based on the measurement of vertical displacements using Laser Rays. Laser Profilometer Bar comprises of two laser sensors used for the measurement of longitudinal profile of two wheel paths of the pavement surface as shown in **Fig. A.2.2**. The system directly gives International Roughness Index (IRI) for both wheel paths viz. Left IRI and Right IRI in terms of m/km. This equipment has self-calibration mechanism.

Fig. A.2.2 Laser Profilometer

3. Fifth Wheel Bump Integrator (FWBI)/Automated Road Unevenness Recorder (ARUR)

Fifth Wheel Bump Integrator **(Fig. A.2.3)** is a response type road roughness measuring system. The equipment consists of a trailer towed by a vehicle. A standard pneumatic tyre wheel inflated to a tyre pressure of 2.1 kg/sqm is mounted within the trailer chassis, with a single leaf spring on either side of the wheel supporting the chassis. Two dashpots provide viscous damping between chassis and axle. The frame is provided with a counter weight at the front to make the device practically free from the effects of the vertical motion of the vehicle. A mechanical integrator makes cumulative measurements of the unidirectional vertical movement of the wheel relative to the chassis. The distance travelled is measured by a distance-measuring unit. The test is conducted at a speed of 32+/-1km/hour. Roughness Index is defined as the ratio of the cumulative vertical displacement to the distance travelled and is expressed in mm/km.

The equipment is driven over the road surface at a speed of 32+/-1km/hour, keeping steady motion and avoiding swerving. The readings of the revolution counter and integrating counters are noted or automatically recorded in the data sheet/logger.

Fig. A.2.3 Fifth Wheel Bump Integrator

The bump integrator values are recorded at preset distance or when the wheel revolution counter records 1000 units which correspond to 1 km. The brief description of the road surface is also noted as the observer travels over the surface. The fifth wheel should preferably travel on wheel path. For measurement of roughness, one measurement in each lane is recommended for riding comforts evaluation. This equipment need to be calibrated and validated with respect to some Class-1 equipment as per the standard procedure.

4. Car Axle Mounted Bump Integrator (CAMBI)

The car axle mounted integrator **(Fig. A.2.4)** consists of a bump integrating unit as provided in the fifth wheel Bump Integrator. The integrating unit is fitted with the rear axle and mounted in the rear portion of the car or rear floor of a jeep.

Fig. A.2.4 Car Axle Mounted Bump Integrator

The differential movement between the rear axle and the body of the vehicle due to road unevenness is measured by the upward vertical motion of a wire which is transmitted into unidirectional rotator movement of the pulley of the integrator unit. There is an arrangement in the integrating unit for converting the rotational movement into electric pulses, which is recorded by the counters/loggers. One count corresponds to 1 cm relative movement between axle and floor of the vehicle. One count in distance counter corresponds to 1 m length of distance travelled.

The road roughness is affected by the vehicle speed. A bump gets magnified if the speed is not maintained. Vehicle load is another factor that influences the roughness measurement. For getting the realistic values, the constant vehicle speed must be maintained (calibration speed) or equipment shall be calibrated for multiple survey speeds. The laden weight of the vehicle is also standardized. While taking measurements, the vehicle should carry maximum three passengers. It should be ensured that the outer vehicle wheel travels on the wheel path. This equipment need to be calibrated and validated with respect to some Class-1 equipment as per the standard procedure.

5. Accelerometer Based (AB) Equipment

Equipment based on the principle of measurement of vertical acceleration of the survey vehicle may also be used for the measurement of road roughness index after due calibration and

validation with respect to Class-1 equipment.

Some portable type of roughness measuring equipment are available which consists of a small accelerometer (sensor) device (one or two) installed at the rear axle of the survey vehicle, a distance measuring instrument, interface module and a controller. The pavement roughness measurements using these equipment are required to be done preferably near to 50 ± 10 km/ hr, in order to obtain most reliable and accurate data. The output is in the units of International Roughness Index (IRI). Another device in this category is measurement of international roughness index using mobile app-based system, this system is based on the use of in-built accelerometer and GPS sensors of the mobile phone and accumulates the vertical displacement, which occurs due to response (Vertical Movement) of the survey vehicle on the test road depending upon road evenness.

Although these-equipment claim to have self calibration mechanism for their accelerometer sensor, but being a response type equipment, it is recommended that such equipment is calibrated/validated for different roughness level covering a wide range of spectrum of surface roughness ranging from very smooth to very rough (say IRI 2.0 m/km to12.0 m/km) with respect to some Class-1 equipment as per the standard procedure.

6. Benkelman Beam

The Benkelman Beam **(A.2.5)** is a simple and inexpensive device for deflection measurements. It was developed at the WASHO Road Test and has been used extensively by highway agencies for pavement research, evaluation and overlay design around the world. The Benkelman Beam consists of a simple lever arm attached to a light weight aluminium frame. Measurements are made by placing the tip of the beam probe between the dual tires of a loaded (8.17 T rear axle) truck at the point where deflection is to be determined. As the loaded vehicle moves away from the test point, rebound or recovery movement of the pavement is measured by the dial gauge. Measurements can be made either by WASHO or CGRA method. The equipment is versatile and simple to operate. However, it is slow and labour intensive. In some cases, particularly on strong pavements, the supporting legs may be within the deflected area resulting in influencing the measurements.

Fig. A.2.5 A Typical View of Benkelman Beam

7. Falling Weight Deflectometer

The deflection device that is receiving much attention now-a-days is the Falling Weight Deflectometer. In principle, this is a very simple device which consists of a weight which falls on a set of rubber buffers that is mounted on a circular foot plate with a diameter of 300 mm. **Fig. A.2.6** gives a schematic representation of the loading and the resulted typical deflection basis. From the description given above, it is clear that FWD produces an impact load. The shape of the load pulse is more or less a half sine, and the duration of the pulse is about 25 milli seconds. The deflections are measured in the centre of the loading plate as well as at various distances from the plate. Normally 7 geophones (velocity transducers) are used, the velocity signal received by geophone is integrated once to obtain the vertical displacement. With respect to the loading plate, it is mentioned that, in principle, this is a stiff plate. At the bottom of the plate, however, a rubber mat is glued to ensure full contact between plate and pavement to ensure uniform stress distribution under the loading plate.

Fig. A.2.6 A Typical View of Falling Weight Deflectometer

8. British Pendulum Tester

It is a simple equipment used for measuring skid resistance of pavement. It is a dynamic pendulum **(Fig. A.2.7)** impact type tester for measuring the resistance offered by a surface under test. It consists of a spring loaded standard rubber slider mounted at one end of the pendulum arm, sliding over the surface under standard conditions. It is used for measuring spot values of surface friction at representative locations. Though it provides good information on the skid resistance of the pavement, it cannot provide data with different speeds.

Fig. A.2.7 British Pendulum Tester

9. Continuous Friction Tester

The continuous pavement friction equipment is used to capture the skid resistance on the pavement surface along the wheel path under wet pavement surface condition. Various continuous pavement friction equipment based on different operating principles as per International Civil Aviation Organisation (ICAO) guidelines are available in the global market. The same equipment is recommend to be used for evaluation of skid resistance on high speed road corridors.

10. Static Wheel Weigh Pads

The static wheel weigh pads are portable, can be easily transported to any site and installed in the field without much of time. The weighing platform consists of two high quality cover plates of metal/alloy having high stiffness and anti-corrosive properties. Load bars or load cells or special load sensors are sandwiched between these cover plates. The weighing pad is connected to the indicator unit which gets power supply through a portable source capable of providing smooth DC supply (maintenance free rechargeable battery). The load cells/load bars have a metal body with foil strain gauges cemented to the body. The digital indicator gives the instant display of load **(Fig. A.2.8)**.

Fig. A.2.8 A Typical View of Static Weight Pad

11. Weigh-in-Motion System (WIM)

There are two types of WIM systems that are currently available globally. One system is permanent type and the other one is portable.

Permanent WIM System

There are a number of permanent WIM systems available. Basically in a permanent WIM system, two weighing platforms rectangular in shape, with slight variation in dimensions from manufacturer to manufacturer, are embedded in the road surface by cutting grooves at appropriate places. Apart from these, there is vehicle detection loop and one platform is located in each wheel path, with associated electronic monitoring system placed on the roadside. Some systems use strain gauge load cells while others use oil-filled piston which acts as a load cell.

Apart from this, there are permanent WIM systems that use peizo weigh sensor, which has a length of peizo electric cable mounted in a U-section channel and encapsulated in the resin. The sensor is set into a slot cut across the traffic lane, with its top face level with the road surface. The buried loop vehicle detector is installed adjacent to the sensors. The entire system when installed gives information on axle load, vehicle classification, gross vehicle weight, vehicle speed, vehicle count, vehicle length etc.

Portable WIM System

The piezo-electric strip sensors provide axle load data. The WIM equipment is automatic weighing and vehicle classification equipment for use at normal highway speeds. The system is capable of measuring vehicle loads and speeds on roads upto four lanes width. The WIM is micro-processor based. The WIM interface and data base computer system provides link with the road sensors. The data collection system is compatible to any computer and stores vehicle records. The user defined reports can be downloaded to an office computer through a floppy diskette/CD. The equipment operates on solar energy or battery powered system.

The road side electronics can also be housed in the experimental van and moved from site to site, as required. The van houses the hardware of the WIM system including solar panel. Besides these the other items useful for continuous work of the staff in the field are also housed inside. The equipment records and provides the information on vehicle weight and axle loads, and speed identification for speed and weight violation etc. The equipment stores the information related to site details, time and date of passage, vehicle index number within the data collection period, vehicle speed, vehicle classification, weight of each vehicle, spacing of vehicles and vehicle length etc. The equipment is ideal for characterisation of 90-100% vehicles even on heavy traffic roads **(Fig. A.2.9)**.

Fig. A.2.9 A Typical View of WIM

12. Ground Penetrating Radar

GPR is most often employed as a technique that uses high – frequency electromagnetic (EM) waves (from 10 MHz to 3000 MHz) to acquire subsurface information. GPR detects changes in EM properties (dielectric permittivity, conductivity, and magnetic permeability), that in a geological setting, are a function of soil and rock material, water content and bulk density. Data are normally acquired using antennas placed on the ground surface or in boreholes. The transmitting antenna radiates EM waves that propagate in the sub surface and reflect from boundaries at which there are EM property contrasts. The receiving GPR antenna records the reflected waves over a selectable time range **(Fig. A.2.10)**. The depths to the reflecting interfaces are calculated from the arrival times in the GPR data if the EM propagation velocity in the sub surface can be estimated or measured.

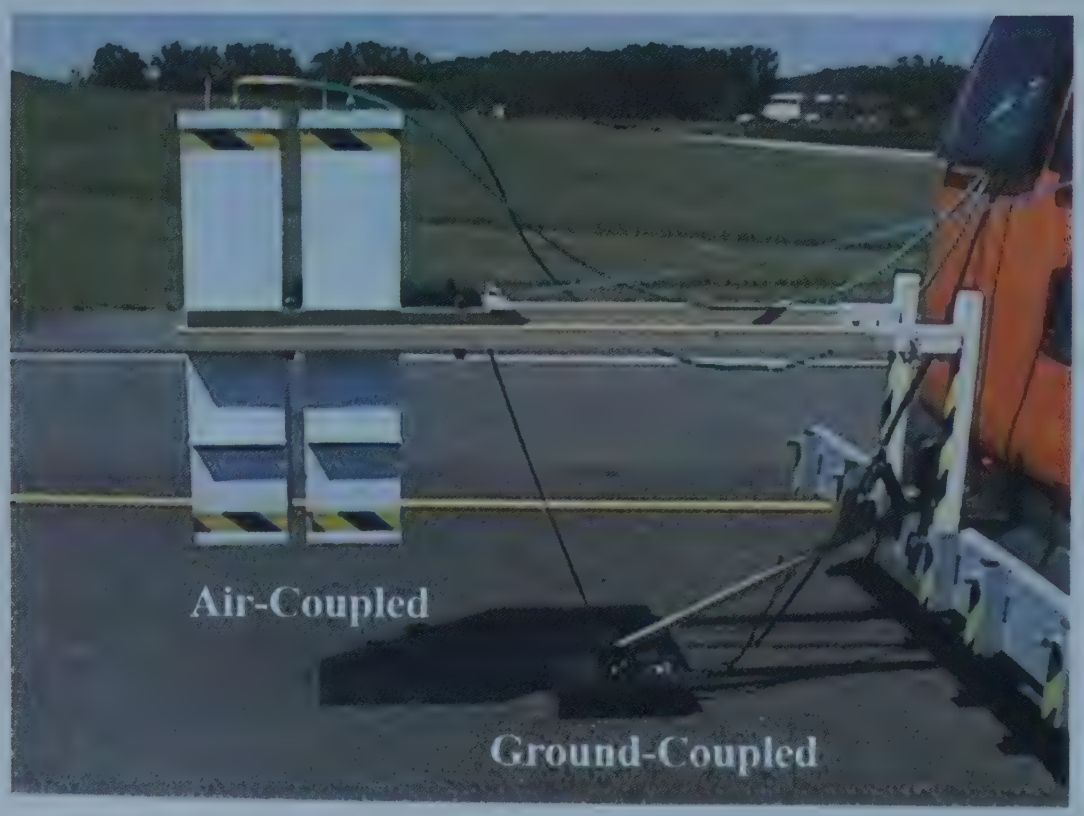

Fig. A.2.10 Evaluation of Pavement Crust Details Using GPR

13. LiDAR

LiDAR is a remote sensing technology which uses laser pulses for the scanning and measure 3D dimension of an object with a 3D Data Capture. It performs point cloud scanning by bombarding millions of laser points and measures the reflected scan. LiDAR can be mounted on various platforms like terrestrial, mobile and airborne, depending upon the object to be scanned. The data accuracy of the LiDAR scanner varies from cm to mm. This accuracy can be obtained as per the requirement of application. The application of LiDAR has a variety of role in roads and highways. The data can be used for various calculation and analysis like pavement analysis, road asset management, road damage assessment, as-built documentation etc. LiDAR captures all road assets like sign boards, signals, tolls plazas, buildings, Utility poles, Cables, divider, etc. with its geo-referenced 3D dimensions along with true pictures. The entire 3D model is developed on the basis of these inputs with high accuracy and further helps decision makers to take effective and robust decision **(Fig. A.2.11)**.

Fig. A.2.11 A Typical View of Mobile LIDAR System

14. Automatic Vehicle Classification/Traffic Counter and Classifier (AVC/ATCC)

A traffic counter and classifier is a device, often electronic in nature, used to count, classify, and/or measure the speed of vehicular traffic passing along a given roadway. The device is usually deployed in near proximity to the roadway and uses an on-road medium, such as pneumatic road tubes laid across the roadway, piezo-electric sensors embedded in the roadway, inductive loops cut into the roadway, or a combination of these to detect the passing vehicles. Pneumatic road tubes are generally used for temporary studies to study a sample of traffic, while piezo-electric sensors and inductive loops are used for permanent studies which can ascertain seasonal traffic trends and are often used in congestion monitoring on major roads.

Formats for data collection and reporting are given in **Appendix – III**

Details of RAMS adopted in some states and NHAI are given in **Appendix - IV**

FORMATS FOR DATA COLLECTION AND REPORTING

P1 - Pavement Inventory Details (Through Secondary Data Collection)

Name and Category of the Road: **Division:**

Section: From Km to Km **State/District:**

Link ID/Name: **Date:**

From (km)	To (km)	RoW	Pavement Type	Carrigeway// Pavement Width (m)	No. of Lanes	Shoulder Width (m)	Shoulder Paved/ unpaved	Shoulder Drop in mm (Left Side)	Shoulder Drop in mm (Right Side)	Side Drainage Condition	Median Width (M)	No. of Junctions	Type of Junctions (T,X, Signalised, Railway level crossings etc.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)

P2 - Pavement Surface Condition

Name and Category of the Road: **Division:**

Section: From Km to Km **State/District:**

Link ID/Name: **Date:**

From (km)	To (km)	Condition year MM/YY	Roughness IRI (m/km)	Total Cracking Area (%)	Ravelled Area (%)	Potholes (no./ km)	Edge Break (m^2/km)	Rut Depth (mm)	Patch Work Area %	Texture Depth (mm)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

P3 - Pavement Crust and Strength Details

Name and Category of the Road: **Division:**

Section: From Km to Km **State/District:**

Link ID/Name: **Date:**

From (km)	To (km)	Surface		Base		Subbase		Subgrade Soil		Height of Embankment (mm)
		Type	Thickness (mm)	Type	Thickness (mm)	Type	Thickness (mm)	Type	CBR	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)

P4 - Pavement Construction and Maintenance History

Name and Category of the Road: **Division:**

Section: From Km to Km **State/District:**

Link ID/Name: **Date:**

From (km)	To (km)	Pavement History								
		Construction		Strengthening (BC+DBM) or (SDBC+BM) etc.		Resurfacing (BC/SDBC etc.)		Preventive Treatment, if any (Fog Seal/Liquid Seal/Sand Seal etc.)		Remarks
(1)	(2)	(3)		(4)		(5)		(6)		(7)
		Year	Specification	Year	Specification	Year	Specification	Year	Specification	

P5 - Classified Traffic Volume Data

Name and Number of the Road:
Section: From Km to Km
Link ID/Name:

Period: (Month/Year): [ ] [ ]

Survey Location:

PWD Circle/Division:
State/District:
Date:

Time	Motorised Vehicles													Non Motorised Vehicles				
	Two Wheelers	Three Wheelers	Cars/ Jeeps	LCV Goods	LCV Passenger	2 Axle Truck	Bus	Semi Truck Trailer	Truck Trailer (Single Rear Axle)	3 Axle Truck	Semi Truck Trailer	Truck Trailer (Tandem Rear Axle)	Truck Trailer (Tridem Rear Axle)	Total Motorised Vehicles	Cycles	Cycle Rikshaws	Animal Carts	Total Non-Motorised Vehicles	Pedestrian
				Code: 1	Code: 2	Code: 3	Code: 4	Code: 5	Code: 6	Code: 7	Code: 8	Code: 9	Code: 10						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)

Note: For Code 1 to 10 Please Refer Vehicle Codes given with Axle Load Survey Format

P6 - Axle Loads Survey Data

Name and Number of the Road:
Section: From Km to Km
Link ID/Name:

PWD Circle/Division:
State/District:
Date:

Sl. No.	Type of Vehicle	Vehicle Code (As per figure)	Wheel Weight (kg.)					
			Front	Rear-1	Rear-2	Rear-3	Rear-4	Rear-5

Vehicle Code	Description	Configuration
1	LCV GOODS (Single /Double Wheeled Rear Axle)	
2	LCV PASSENGER (Single / Double Wheeled Rear Axle)	
3	2 AXLE TRUCK	
4.	BUS	
5	SEMI TRUCK TRAILER (Single Rear Axle)	
6	TRUCK TRAILER (Single Rear axle)	
7	3 AXLE TRUCK	
8	SEMI TRUCK TRAILER (Tandem Rear Axle)	
9	TRUCK TRAILER (Tandem Rear Axle)	
10	TRUCK TRAILER (Tridem Rear Axle)	

P7 - Pavement Geometrics Data

Name and Category of the Road:
Section: From Km to Km
Link ID/Name:

Division:
State:
Period (year/month):

From (km)	To (km)	Rise + Fall (m/km)	No. of Rises & Falls (km)	Horizontal Curvature (deg/km)	Cross Slope (%)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)

CD1 - Inventory on Cross Drainage Structures

Name and Category of the Road:
Section: From Km to Km
Link ID/Name:

PWD Circle/Division:
State/District:
Date:

From (km)	To (km)	Culvert Details			Bridge Details									
		Type of CD (Pipe/Slab/ Arch)	No. of Pipes/ Diameter/ No. of Spans, etc.	Length of Structure (m)	Type of Foundation	Type of super/sub-structure	Name of River/Drain	Type	Length	Length of Span	Carriageway width	No. of Span	Year of construction	Other including Causeways/ Railway bridges
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)

Appendix – IV
(Para 14)

DETAILS OF RAMS ADOPTED IN SOME STATES AND NHAI
OVERVIEW ON ODISHA ROAD ASSET MANAGEMENT SYSTEM (ORAMS)

The road network of Odisha Works Department (OWD) comprises of 4848 km of National Highways, 4104 km State Highways, 2817 km Major District Roads, 18869 km of Other District Roads totalling to 30638 km. In order to effectively prioritise works based on technical parameters and to improve the quality and delivery of OWD services in the management of the state road network, the department has developed and commissioned "Odisha Roads Asset Management System (ORAMS)" in the year 2015. The World Bank has assisted OWD to develop this objective maintenance planning and resource allocation system for road maintenance under Institutional Development component of World Bank Aided Odisha State Roads Project.

A Planning and Road Asset Management Cell has been established within OWD since 2015 for Planning, and Programming of road works. The RAM Cell is headed by the Chief Engineer (Design, Planning, Investigation and Roads) with Superintending Engineer (Planning), Executive Engineer (Planning & AMS), Deputy Executive Engineer/Asst. Executive Engineer/Assistant Engineer/Junior Engineers to look after various activities required for ORAMS such as collection of inventory and condition data, running of ORAMS modules, reporting and budgeting activities etc. The technical team is supported by a dedicated IT support team comprising of Programmer, Database Administrator and GIS personnel.

The core of the ORAMS is a web based Road Information System (RIS) and Bridge Information System (BIS). These are series of databases linking different road and bridge data items. It is accessed from a centrally linked server, (which is currently housed in OWD head office at Nirman Soudha) which is independent of any network. The system is designed for multi-level user requirements (i.e. 1. Headquarters and, 2. Circle/Division) as well as the general public through the internet) with appropriate security, interfaces and reporting facilities appropriate to the level of the user. There are number of applications developed to address the various requirements of road and bridge asset management having interface with the RIS-BIS. These applications are designed, based on the specific requirements of the different management processes.

The ORAMS has been developed by configuring the commercial-of-the-shelf products:

1. For a core database engine
2. Database Middleware Software application configured to store and process data related to roads, bridges, traffic and to store spatial data
3. The Highway Development and Management (HDM-4) analytical tool used to predict the road condition and suggest treatments by a life-cycle costing method using analytical engine for different years
4. An interface Software to transform data from the database to HDM-4 accepted data input format
5. GIS server and Desktop Software applications used as GIS platform for all spatial features of the road assets and

6. Information Manager application for Portal Base reporting.

The system architecture and Implementation Architecture of ORAMS are shown at **Fig. B.1** and **Fig. B.2** respectively.

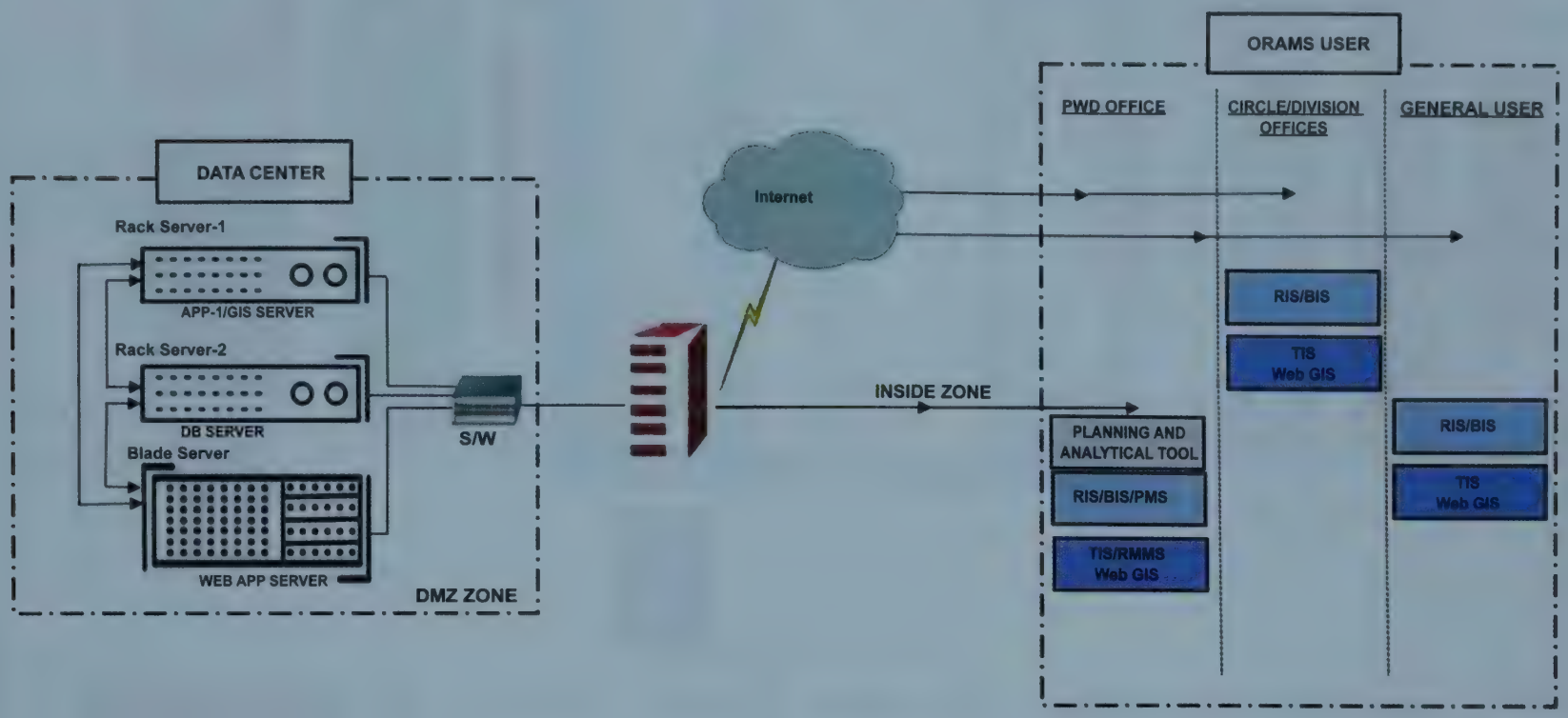

Fig. B.1 System Architecture of ORAMS

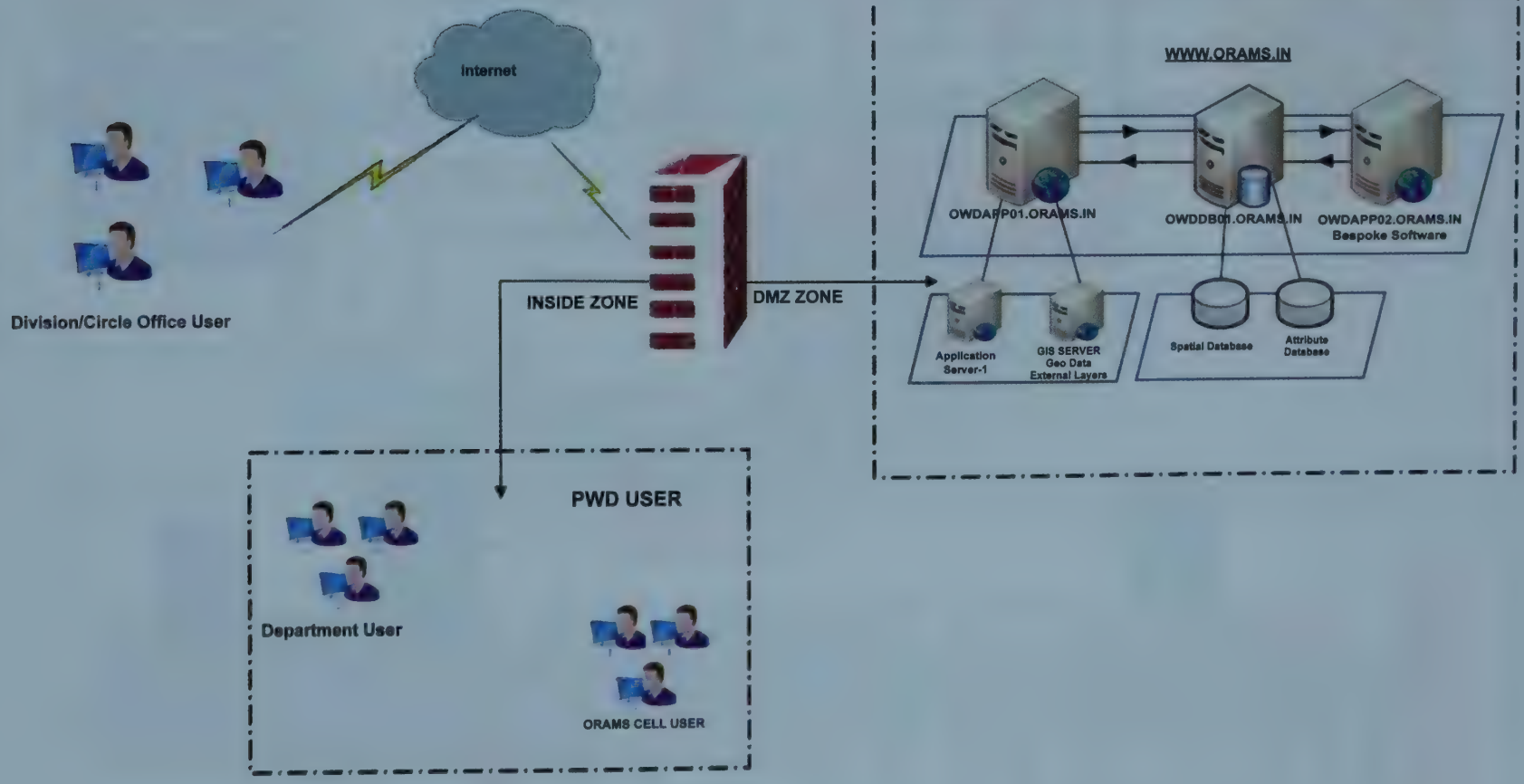

Fig. B.2 Implementation Architecture of ORAMS

The system dataflow showing the above applications is shown in **Fig. B.3**

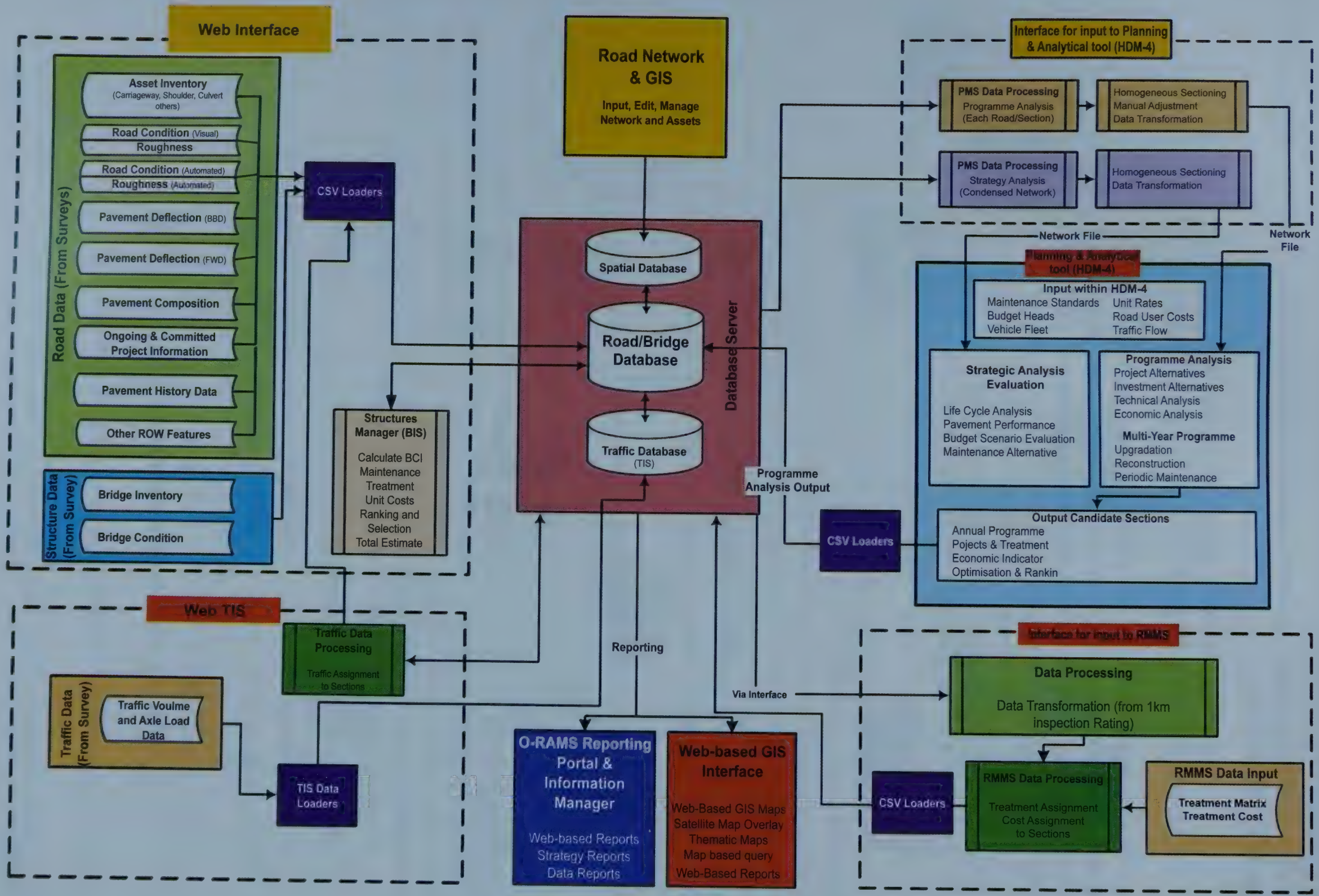

Fig. B.3 System Data Flow of ORAMS

The developed system has been installed in the servers located within the OWD premises at Nirman Soudha. The details of the servers with ORAMS application are presented below.

Server Name	RAM Size	HDD Size	Processor	Process Code Details	OS Platform	Server Type
APPLICATION & GIS SERVER	32GB	560GB	Multi Core Next Generation Processor	4	Windows	Rack Server
DATABASE SERVER	32GB	560GB	Multi Core Next Generation Processor	4	Windows	Rack Server
WEB APP SERVER	16GB	280GB	Multi Core Next Generation Processor	8	Windows	Blade server

The web based ORAMS hoisted in servers of OWD is accessible to the public through the URL http://orams.in/. A screenshot showing the modules of ORAMS is shown in **Fig. B.4**:

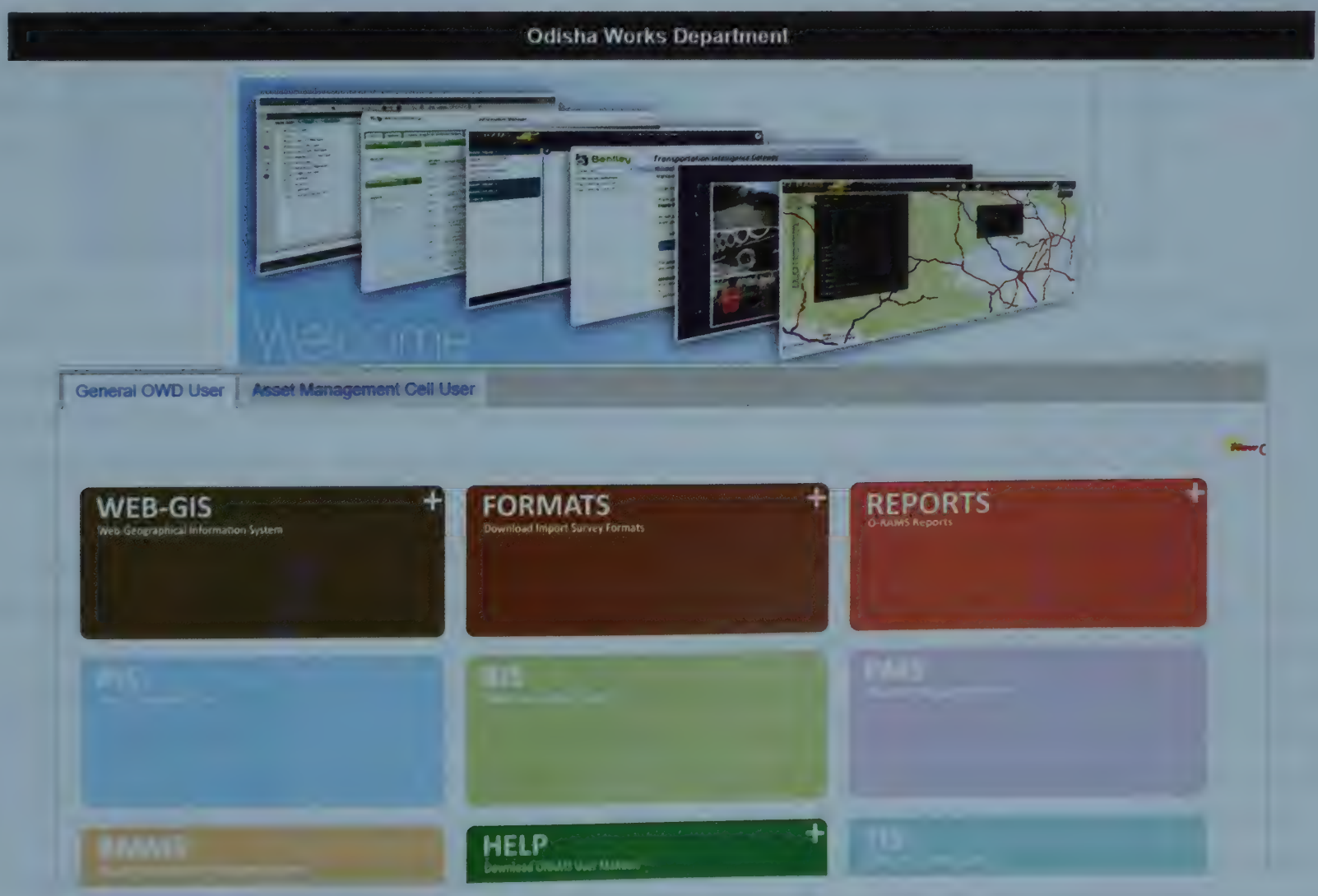

Fig. B.4 Asset Management Cell user web page of ORAMS

The present web based ORAMS has the following applications:

A. For OWD Users

1. Road Information System (RIS) for Road Network and Data Management.
2. Bridge Information System (BIS) for Bridge Inventory and Condition.
3. Pavement Management System (PMS) for Interface to HDM-4.
4. Traffic Information System (TIS) for Traffic Data processing for RIS/PMS modules.
5. Routine Maintenance Management System (RMMS) for Estimate for Routine Maintenance Requirements.

B. For Public Users

Web-GIS View and Reporting Tools for GIS based search, satellite image overlay, thematic maps

1. Road Information System (RIS): The Road Information System (RIS) is the principal module of O-RAMS. It consists of web-based applications designed to input/ upload, store, edit, update, view, download the road network and asset data such as Carriageway, Shoulders, Pavement Composition, Pavement Condition, Roughness etc. It also manages Users of the system, their roles and jurisdiction access.
2. Bridge Information System (BIS): Bridge Information System (BIS) is a web-based application, designed to input/upload, store, edit, update, view, download the bridge inventory, inspection data, photographs of bridges, documents referenced over the road network.
3. Pavement Management System (PMS): Pavement Management System (PMS) consists of tools to ascertain maintenance requirements for OWD road network. A Planning and Analytical tool, namely Highway Development and Management (HDM-4) analytical tool, is used to predict road condition and suggest treatments by a life-cycle costing method using analytical engine for different years.

   To supply data to HDM-4 the data held within road database such as road inventory, composition, pavement inspection, roughness, structural strength and traffic are converted to a format acceptable by HDM-4 analytical tool, using an interface application software; This software is configured to extract data from the database, prepare homogenous sections based on user defined parameters, and transform the data to representative values in the format acceptable to perform programme and strategy analysis using HDM-4.
4. Traffic Information System (TIS): The Traffic Information System (TIS) is a web-GIS-based custom built application, designed to input, store, manage, analyse and report traffic volume and axle-load data.
5. Routine Maintenance Management System (RMMS): Routine Maintenance Management System (RMMS) is a web-based custom built application, designed to determine on-carriageway routine maintenance requirements for sections not receiving any improvements for a year and prepare routine maintenance budget required for a section, division or a circle. Routine maintenance is a regular activity which is carried out throughout the year based on fund allocated.

Data Collection for ORAMS:

i. GIS Data Collection

The key feature of ORAMS is its GIS based information system for all roads and bridges under the administrative control of OWD and the availability of the same to public through online portal, i.e orams.in. This GIS based information system for road and bridges have been developed from the satellite imageries of road network. These data are procured by the OWD from Remote Sensing Agencies of Govt. of India, such as Orissa Remote Sensing Application Centre (ORSAC). The last updated orthorectified geo-referenced satellite data procured from ORSAC is during 2018.

Besides, the field engineers are trained to collect the spatial information of the new roads, (in the event of transfer of any road from other Department to OWD) using a Hand Held GPS or GPS enabled mobile handset using suitable application. The spatial data collected from the field, is then validated using the satellite imageries available with ORSAC by the Asset Management Unit before uploading the same in the ORAMS web portal for information of General Public. Tools used for GPS data collection are shown **Fig. B.5**.

a. Image showing a Typical Hand Held GPS

b. Image showing Capturing GPS information using suitable application in GPS enabled mobile hand set

Fig. B.5 Tools used for GPS Data Collection

ii. Inventory Data Collection

Collection and updation of annual data on road inventory has got significant role in the sustainability of the Asset Management system. Hence, an office order has been issued to all field divisions to collect and submit the Inventory Data of all new Roads, new Bridges & new Culverts, under their respective jurisdiction, taken over to the PWD Book of Accounts in the preceding Financial Year. Formats for data collection have been developed and shared through the web portal of ORAMS, i.e through the FORMAT module of the Portal. Field staffs are trained to access the format using the ORAMS web portal, update the requisite information in the prescribed excel file format available through the web-portal and communicate the updated data to the centralised

unit through proper channel for uploading of the information to the Database of ORAMS. The inventory information so collected, after due verification, is made available through the Web-GIS module for better appreciation.

iii. Road Condition Data Collection

The collection of condition data has been outsourced. The Condition Data of the Road Assets are being collected annually on the road network through Automated Road Surveying Systems (ARSS) vehicle shown at **Fig. B.6**. This network survey vehicle fitted with DGPS, Digital Camera for Pavement, Laser Profilometer, Rut Scanner, Road Geometry Measurement equipment captures condition data such as Cracking, Ravelling, Pothole, Rutting, Roughness etc. alongwith the other inventories of the road. A typical road data condition output after survey through ARSS vehicle is presented at **Fig. B.7**.

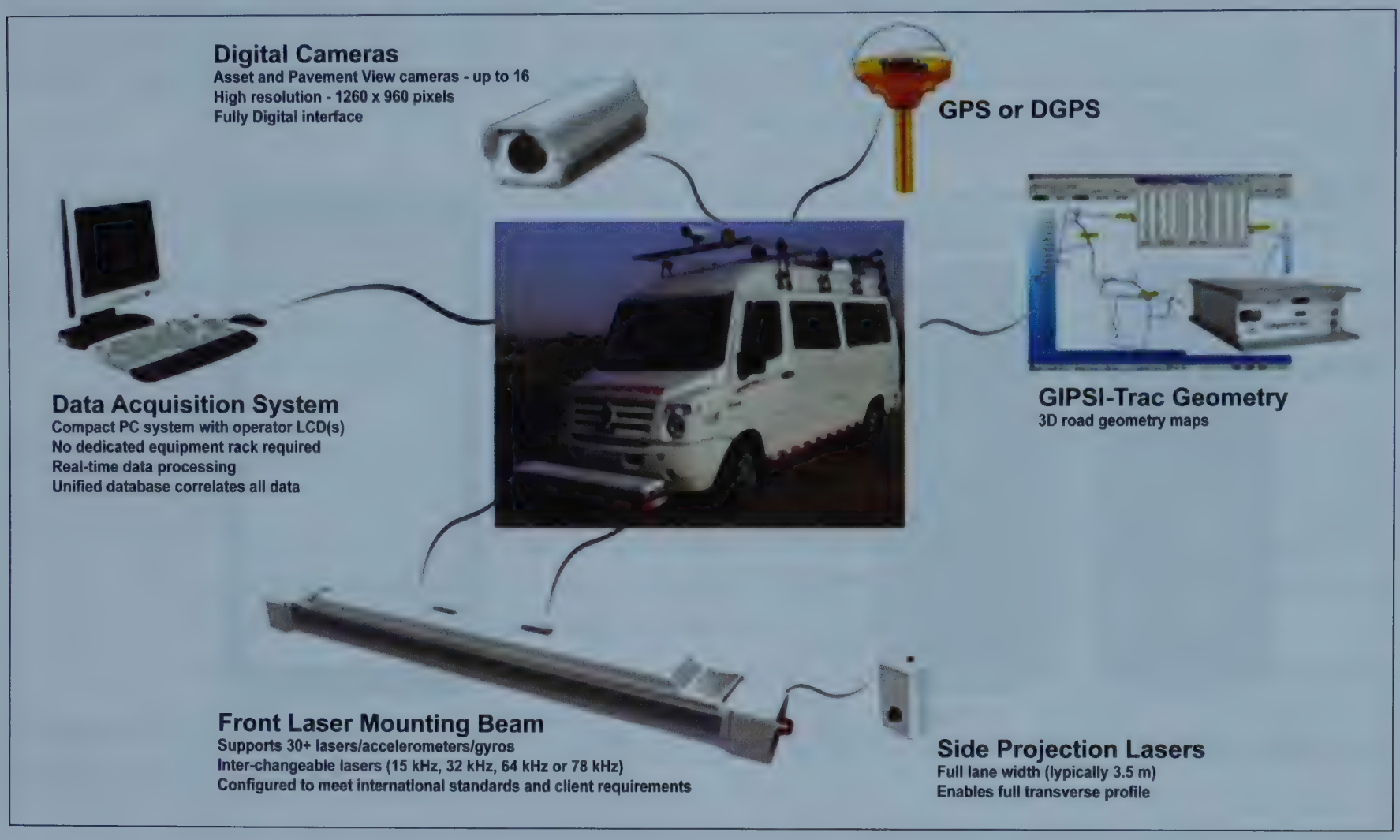
Digital Cameras
Asset and Pavement View cameras - up to 16
High resolution - 1260 x 960 pixels
Fully Digital interface
GPS or DGPS
Data Acquisition System
Compact PC system with operator LCD(s)
No dedicated equipment rack required
Real-time data processing
Unified database correlates all data
GIPSI-Trac Geometry
3D road geometry maps
Front Laser Mounting Beam
Supports 30+ lasers/accelerometers/gyros
Inter-changeable lasers (15 kHz, 32 kHz, 64 kHz or 78 kHz)
Configured to meet international standards and client requirements
Side Projection Lasers
Full lane width (lypically 3.5 m)
Enables full transverse profile

Fig. B.6 Automated Road Surveying Systems Vehicle used for Data Collection in Odisha

BHANJANAGAR

Table 5A Road Inventory and Pavement Condition (Tillisingi to Gallary) MDR-1467

Chainage (km)		IRI (m/km)	Rut Deth (mm)	Texture Depth (mm)	Ravelling (sqm)	Cracking (sqm)	Loss of surface Material (sqm)	Pothole (sqm)	Grade (%)	Rise+Fall (m/km)	Rise+Fall (No./km)	Horizontal Curvature (deg/km)	Cross Slope (%)	Speed (Km/h)	Latitude (deg)	Longitude (deg)	Altitude (m)	Survey Day	Time	Road Width
0.000	1.000	9.8	7.4	1.6	0.0	2.6	45.9	0.0	0.4	4.7	13	106.6	4.0	39.7	20.022796	84.624592	96.4	12 May-18	12:47:22	5.500
1.000	2.000	12.6	14.5	2.1	1.4	15.1	108.3	0.6	0.5	5.4	9	46.4	4.5	30.4	20.031720	84.622295	98.4	12 May-18	12:47:22	5.500
2.000	3.000	11.9	16.8	2.2	5.6	41.5	156.9	5.4	0.4	5.2	4	19.5	5.0	30.9	20.040291	84.618845	103.2	12 May-18	12:47:22	5.500
3.000	4.000	12.1	9.1	1.5	0.9	6.6	27.9	3.4	0.3	7.6	12	96.3	2.6	24.5	20.048705	84.615292	100.5	12 May-18	12:47:22	5.500
4.000	5.000	11.4	16.9	1.6	0.0	19.3	12.3	1.4	0.5	7.3	17	31.5	4.9	36.6	20.057484	84.612555	100.7	12 May-18	12:47:22	5.500
5.000	6.000	13.2	16.6	1.9	2.0	72.2	92.6	1.5	0.5	9.0	11	141.0	4.9	34.1	20.064945	84.608789	107.0	12 May-18	12:47:22	5.500
6.000	7.000	13.2	10.5	1.6	0.0	23.8	16.7	2.1	0.6	8.4	9	141.5	3.4	34.1	20.072719	84.604379	112.2	12 May-18	12:47:22	5.500
7.000	8.000	13.0	14.6	1.9	0.8	44.3	60.1	0.0	0.4	8.8	15	20.1	4.5	40.7	20.079868	84.598286	109.5	12 May-18	12:47:22	5.500
8.000	9.000	14.6	12.0	1.6	4.0	7.4	210.7	0.0	0.6	12.1	7	145.5	3.2	27.6	20.083029	84.589985	117.5	12 May-18	12:47:22	5.500
9.000	10.000	15.0	13.7	1.8	0.0	28.8	192.7	1.5	0.1	7.1	12	46.4	4.4	30.8	20.086657	84.581216	117.0	12 May-18	12:47:22	5.500
10.000	11.000	10.6	6.9	1.7	0.0	0.0	3.2	0.6	0.6	7.1	8	28.1	3.5	40.0	20.089530	84.571999	120.9	12 May-18	12:47:22	5.500
11.000	12.000	10.0	5.0	1.2	0.0	0.0	0.0	0.7	0.5	7.3	12	268.1	1.4	30.5	20.095734	84.570159	117.1	12 May-18	12:47:22	5.500

Fig. B.7 Sample Data Collection Output after Survey using ARSS Vehicle

In case automated method of data collection is not feasible on a specific road stretch, then visual/manual mode of data collection is being resorted to and the field staff have been trained to collect condition data by visual/manual mode.

Similarly, the structural strength data are being collected through Falling Weight Deflectometre (FWD) through the outsourced data collection mechanism. A view of FWD of CRRI used in Odisha is shown in **Fig. B.8**.

Fig. B.8 Falling Weight Deflectometer used in Odisha

iv. Traffic Data Collection

Field Divisions provide the annual three-day Traffic Volume data after survey at identified Traffic Count stations. Field staffs have been trained about the methodology of Traffic volume data collection. Formats for traffic data collection have been shared through the format module of the ORAMS web portal. Accordingly, Traffic Volume data have been received from time to time and updated in ORAMS data base.

ORAMS output

1. Routine Maintenance and Management Assessment

The routine maintenance requirement of a road stretch are assessed using the Routine Maintenance and Management System (RMMS) module of ORAMS. The RMMS determines the maintenance requirement of the road stretch based on the present condition i.e type of distress, severity and extent of distress, approved treatment measures, unit cost of treatment. Typical output of RMMS as derived from ORAMS for a sample road is shown at **Fig. B.9**.

Routine Maintenance Management Data
Year : 2018
Bolangir

CHAINAGE		CWAY WIDTH (m)	CWAY TYPE	CRACKING				POTHOLE				RAVELLING				RUTTING				MISC. COST (Rs.)	TOTAL COST (Rs.)
From (km)	To (km)			Quantity (sqm)	Treatment	Unit Cost (Rs.)	Total Cost (Rs.)	Quantity (sqm)	Treatment	Unit Cost (Rs.)	Total Cost (Rs.)	Quantity (sqm)	Treatment	Unit Cost (Rs.)	Total Cost (Rs.)	Quantity (sqm)	Treatment	Unit Cost (Rs.)	Total Cost (Rs.)		
Deogaon-Tikirapara Road																					
Up																					
		Lane 1																			
0.000	1.000	5.5	BT									1.05	TC+PMC+SC	193.00	202.65					35000.00	35202.65
1.000	2.000	5.5	BT													14.40	TC+PC	136.00	1958.40	35000.00	36958.40
2.000	3.000	5.5	BT													14.40	TC+PC	136.00	1958.40	35000.00	36958.40
3.000	4.000	5.5	BT													14.40	TC+PC	136.00	1958.40	35000.00	36958.40
4.000	4.300	5.5	BT													14.40	TC+PC	136.00	587.52	10500.00	11087.52
4.300	4.450	5.5	BT													14.40	TC+PC	136.00	293.76	5250.00	5543.76
4.450	5.000	5.5	BT													14.40	TC+PC	136.00	1077.12	19250.00	20327.12
5.000	5.390	5.5	BT																	13650.00	13650.00
5.390	5.660																			9450.00	9450.00
5.660	6.000																			11900.00	11900.00
6.000	7.000																			35000.00	35000.00
7.000	8.000																			35000.00	35000.00
8.000	9.000	5.5	BT	59.10	Seat Coat Using CRMB60	55.00	3250.00													35000.00	38250.50
9.000	10.000	5.5	BT	46.80	Seat Coat Using CRMB60	55.00	2574.00					1.05	TC+PMC+SC	193.00	202.65	14.40	TC+PC	136.00	1958.40	35000.00	39735.05
10.000	11.000	5.5	BT	67.20	Seat Coat Using CRMB60	55.00	3696.00					0.75	TC+PMC+SC	193.00	144.75	14.40	TC+PC	136.00	1958.40	35000.00	40799.15
11.000	11.288	5.5	BT									0.75	TC+PMC+SC	193.00	41.69	14.40	TC+PC	136.00	564.02	10080.00	10685.71
12.000	12.050	5.5	BT																	1750.00	1750.00
12.050	12.350	5.5	BT																	10500.00	10500.00
12.350	13.000	5.5	BT																	22750.00	22750.00
13.000	14.000	5.5	BT									3.30	TC+PMC+SC	193.00	636.90	14.40	TC+PC	136.00	1958.40	35000.00	37595.30
14.000	14.800	5.5	BT													14.40	TC+PC	136.00	1566.72	28000.00	29566.72
14.800	15.000	5.5	BT													14.40	TC+PC	136.00	391.68	7000.00	7391.68
15.000	16.000	5.5	BT													14.40	TC+PC	136.00	1958.40	35000.00	36958.40
16.000	17.000	5.5	BT									1.20	TC+PMC+SC	193.00	231.60					35000.00	35231.60
17.000	18.000	5.5	BT	3.60	Seat Coat Using CRMB60	55.00	198.00					34.05	TC+PMC+SC	193.00	6571.65	14.40	TC+PC	136.00	1958.40	35000.00	43728.05
18.000	19.000	5.5	BT									6.30	TC+PMC+SC	193.00	1215.90					35000.00	36215.90
19.000	20.000	5.5	BT																	35000.00	35000.00

Fig. B.9 RMMS Output for a Sample Road showing details of Maintenance Treatment and Costing

2. Pavement Management System (PMS)

For managing periodic and capital road works activities a Pavement Management System (PMS) application has been developed. The core of the PMS currently being used in ORAMS is HDM-4 software (i.e. a Highway Development and Management tool globally used by World Bank and other multi-lateral funding agencies). The HDM-4, as an integral part of ORAMS, is a user-friendly desktop application for PMS. The engineering and economic analytical tool of HDM-4 include deterioration prediction model for both bituminous and concrete pavement and life cycle cost analysis to facilitate decision making in case of both constrained budgetary scenario. A network level PMS output derived from ORAMS is shown at **Fig. B.10**.

Proposed PMS Work Summary
For Division Anugul, Year 2017
and Analysis Year : 2016

Road Name	Category	Carriageway Up/Down	Length (km)	Work							
				Periodic Renewal		Overlay		Strengthening		Widening	
				Length (km)	Cost (Rs. in Lakh)	Length (km)	Cost (Rs. in Lakh)	Length (km)	Cost (Rs. in Lakh)	Length (km)	Cost (Rs. in Lakh)
Budget Scenario : Unconstrained											
Angul-Chhendipada-Sarpal-Budhapal road	SH	Up	39.464	1.464	48.99					11.000	1267.46
Angul-Tikarpada road	SH	Up	47.391	3.700	123.80	42.000	2087.52				
Angul-Maidharpur road	SH	Up	17.549	1.000	17.49					4.000	478.08
Angul-Ekhagharia-FCI road	ODR	Up	8.9	5.200	110.32						
Angul-Sankhapur-karatapata road	ODR	Up	18.563	13.000	341.77						
Thakrugarh-Nakchi road	ODR	Up	17.235	14.000	244.93	2.550	126.74				
Talcher-Angul Border road	ODR	Up	5.092	1.242	21.67						
Handidhua junction to FCI road	ODR	Up	5.324			5.324	506.10				
Talcher Gopalprasad Kaniha road (Talcher to Gopalprasad)	ODR	Up	16.194			12.050	1108.81	4.144	372.65		
Kaniha-Kakudia road	ODR	Up	10.678	4.170	90.54	4.500	223.66				
N.H. 6 to Jharbeda road	ODR	Up	13.565			7.660	380.72				
N.H. 6 to Jamardihi road	ODR	Up	17.987							8.820	1054.17
Nathurpasi to Pangatira road	ODR	Up	22.001	5.020	87.82	6.256	310.94				
Parsumal Kishorenagar road	ODR	Up	19.857	15.645	411.31	1.159	86.57				
Total :				**64.441**	**1498.65**	**81.499**	**4831.06**	**4.144**	**372.65**	**23.82**	**2799.71**

Fig. B.10 Output at Network Level for a Sample Road Network

OVERVIEW OF KARNATAKA ROAD MANAGEMENT SYSTEM (KRAMS)

Public Works, Ports and Inland Water Transport Department has the responsibility for the development and maintenance of National Highways, State Highways, Major District Roads and Village Roads and construction and maintenance of Government Buildings. The road network in Karnataka comprises 6,977 km of National Highways (NH), 19,578 km of State Highways (SH), 49,909 km of Major District Roads (MDR), and 147,212 km of Village Roads (VR). Insufficient funding for road maintenance and lack of an objective data-driven process for prioritisation of roads and allocation of funds had increased the number of roads that are beyond maintainable condition.

Over the years, Government of Karnataka has initiated various programmes with assistance from ADB and World Bank to develop, improve and maintain the transportation infrastructure. One of the main objectives of Karnataka State Road Policy, launched in 2009, was to strengthen the institutions in the road sector for orderly, efficient and regulated development of the sector and maintenance of its assets. A joint mission of ADB and World Bank in June 2010 held extensive discussions with PWP & IWTD and agreed upon an Institutional Development and Strategy Action Plan (IDSAP). One of the principal features of the IDSAP was the establishment of a Planning and Road Asset Management Centre (PRAMC) in PWP & IWTD.

PWP & IWTD established Planning and Road Asset Management Centre (PRAMC) whose functions include Policy Development and Planning, Programming, Road safety, Information Technology support across the whole of PWP & IWTD and Training support across whole of PWP & IWTD.

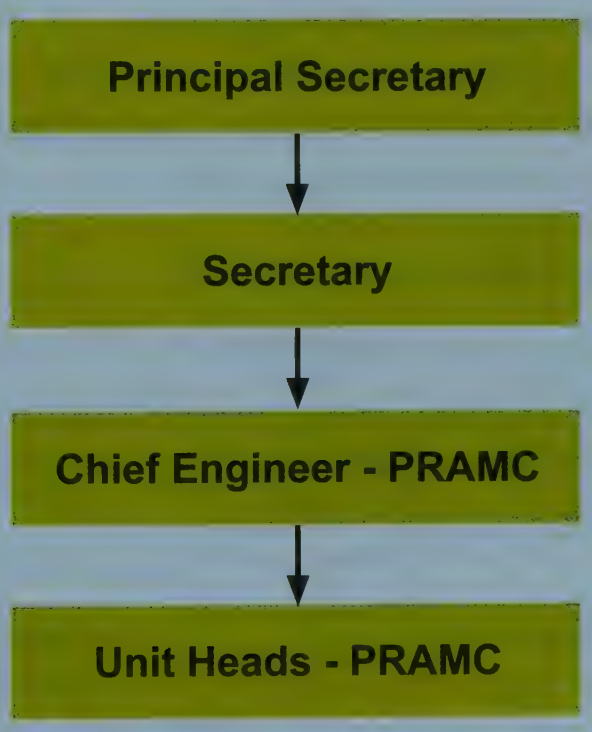

Fig. B.11 PRAMC Organisational Hierarchy

Planning and Road Asset Management Centre is a cohesive central office for Planning, Budgeting, and Programming of public roads in Karnataka. At the Secretariat, PRAMC is headed by a Principal Secretary and a Secretary. Chief Engineer is the administrative and professional Head of the PRAMC as shown in the above **Fig. B.11**.

Planning and Road Asset Management Centre acts as Sector Apex body for policy development, planning and programming related to development, maintenance and management of road assets, with the following core functions:

- Preparation of Annual Works Program and infrastructure budgets for PWP & IWTD,
- Act as a Road Safety Cell for PWP & IWTD by coordinating road safety activities in PWP & IWTD,
- Improved decision making capability in the context of a rational framework,
- Improved planning, budget preparation and programming of public road works,
- Technical based decision making process (Engineering, Economic, Social, Environmental factors),
- Cost effective road network planning and infrastructure asset management,
- Preparation of Social and Environmental policies,
- Improve staff development and training in PWP & IWTD to help sustain the new processes.

Specific Functions of Policy and Planning Unit

- Management of roads and bridges,
- Preparation of road network development plans,
- Identify investment interventions on the basis of economic efficiency criteria ("value for money") under constrained budgets,
- Provide inputs to the PWP & IWTD planning and annual budgeting process,
- Perform project level and programme level analyses using the Highway Development and Management (HDM-4) software modelling tool,
- Improve the management and inspection of bridges and the planning of bridge rehabilitation and maintenance interventions,
- Implementation and execution of specialised asset management system software tools including Pavement Management System (PMS), Bridge Management System (BMS) and other systems of KRAMS.

Functions of Programming and Monitoring Unit

- Evaluate and prioritise projects for inclusion in Annual Works Programme,
- Preparation of Annual Works Program and infrastructure budget,
- Monitor the progress of annual works programme implementation and execution,
- Monitor the procurement of Right-of-Way.

Functions of Road Safety Unit

- Act as a single office for coordinating all road safety functions of PWP & IWTD and improve coordination among various stakeholders including traffic police, health care agencies, education agencies and the Transport Department,
- Road accident data collection and data quality assurance,
- Implementation and execution of specialized Traffic Incident Management System software tool,
- Conduct black spot analysis and preparation of an annual black spot rectification programme,
- Carry out Road Safety Audits,
- Compilation and collation of all road traffic accident statistics.

Functions of Information Technology Unit

- Provide technical support for planning, procurement, implementation and integration with IT systems across PRAMC and PWP & IWTD including the various management system applications,
- IT budgeting and procurement,
- User account and band width management,
- Firewall management and intrusion detection,
- Server monitoring and backup and recovery,
- Desktop policies and security,
- End User Support and training,
- Development and management of Intranet services.

Functions of Training Unit

- Identify training needs across PWP & IWTD,
- Identification of training courses (internal and external),
- Preparation of an annual training calendar,
- Advertise and schedule training courses,
- Record staff completion of courses and training,
- Monitor effectiveness of training courses and employee feedback.

The PRAMC Process Management System (PPMS) is designed as a system of interrelated processes as shown in **Fig. B.12**. Quality System Processes and their sub-processes are clearly documented in the quality manual and in associated operational procedures and work instructions. QMS documentation also defined criteria and methods needed to ensure that the operation and control of PPMS processes are effective. This includes assignment of responsibilities and allocation of resources for each process, instructions on how to perform the process, and definition of methods for monitoring and/or measuring the effectiveness of the process.

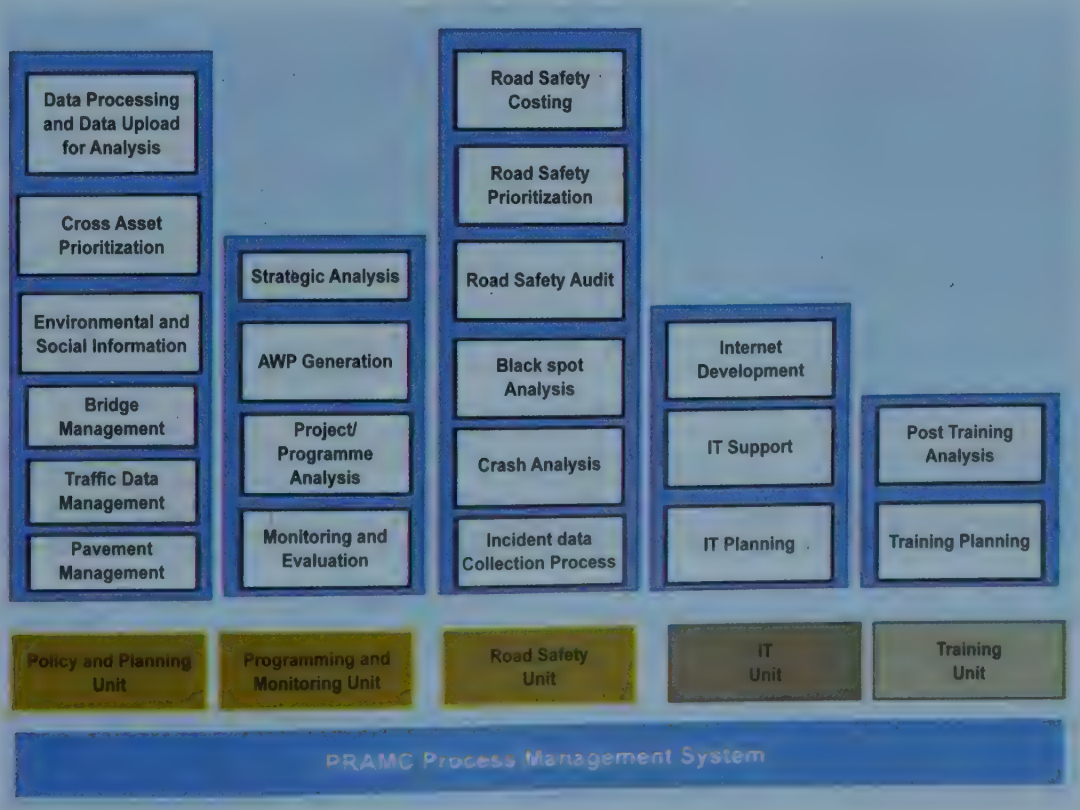

Fig. B.12 PRAMC Process Management System

PRAMC is responsible for planning, programming and monitoring the road maintenance works on the PWD & IWTD road network. Within the overall road network of the state, the Government of Karnataka (GoK) identified an initial Core Road Network (CRN) of approximately 25,000 km. This CRN comprises the mix of road links of National Highways (NH), State Highways (SH), Major District Roads (MDRs), which are considered most important for the economic and social development of the State. The composition of the CRN is as below:

Road Type	Length (km)
National Highways	6,196
State Highways	17,103
Major District Roads	1,283
Total Length (km)	**24,582**

Bridge Type (Length)	Number
Major (>=60 m)	236
Minor (>=6 m and <60 m)	2,998
Total Length (km)	**3,234**

PRAMC procured the following state-of-the-art and international standard equipment for collection of inventory and condition data:

- Laser based Road Condition Data Collection Vehicle (RCDCV)
- Falling Weight Deflectometer (FWD)
- Ground Penetration Radars (GPR)
- Bridge Inspection Vehicle (BIV)

Laser based Road Condition Data Collection Vehicle (RCDCV)

PRAMC procured Laser based Road Condition Data Collection Vehicle (RCDCV), as shown in **Fig. B.13** for collecting high accuracy and reliable data road inventory and pavement condition data. The equipment comprises of Distance Measuring Instrument (DMI for accurate measurement of linear distance), Differential correction enabled GPS receiver for recording Road Alignment, Dual wheelpath Laser Profilers (for measuring Roughness and Texture), Laser Rut Measurement System (LRMS for accurate measurement for Rut Depth), High Definition Video Cameras (for recording Right of Way view) and High Resolution Pavement Camera for recording pavement surface view, Rating keyboards for rating surface defects using semi-automated method.

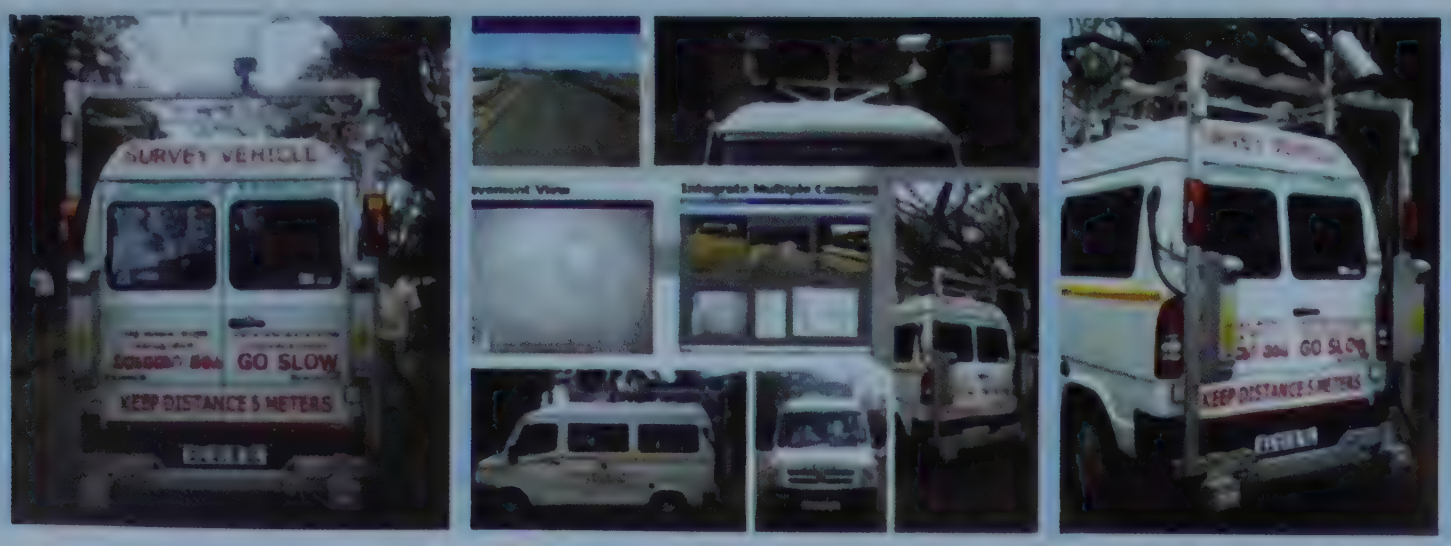

Fig. B.13 Laser Based Road Condition Data Collection Vehicle

Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR)

Vehicle mounted Falling Weight Deflectometer (FWD) was procured to collect pavement deflection and layers elasticity moduli. GPR is used to collect continuous pavement composition

(layers). Both FWD and GPR installed on the same vehicle and collected the deflection and pavement layers simultaneously as shown in **Fig. B.14**.

Fig. B.14 FWD and GPR Equipment

Bridge Inspection Vehicle (BIV)

A bucket type Bridge Inspection Vehicle (BIV) as shown in **Fig. B.15** mounted on a suitable truck for Indian conditions with operating range of up to 12.0 m width of Bridge, lowering depth 16.50 m below Bridge Deck and working height 15.20 m above in Overhead mode and 3 booms to give boom rotation of 180° procured for accurate assessment for the physical and functional condition of Bridges. This BIV has the facility to reach under parts and sides of the bridges where deterioration remains generally unnoticed. This is used to assess the condition of the structure in detail and conduct the Non Destructive Testing (NDT) of Bridges at critical components (such as the Sofit and bearing locations etc) without any effect or with very minimal disruption to traffic movement over the bridge.

Fig. B.15 Bridge Inspection Vehicle

The Karnataka Road Asset Management System (KRAMS) is a comprehensive and integrated software application, as shown in **Fig. B.16**, developed by configuring commercial-of-the-shelf system (COTS), existing web based Road Information System (RIS), HDM-4 and Transport Modelling Tool (TMT) designed to assist PRAMC in providing enhanced and streamlined management of roads under its jurisdiction. This tool is assisting PWP & IWTD in utilising public funds more effectively and efficiently, while maintaining the road network at acceptable levels of service. The KRAMS supports both manual and automated equipment based data collection, data storage and processing of data for the network under the jurisdiction of PWP & IWTD.

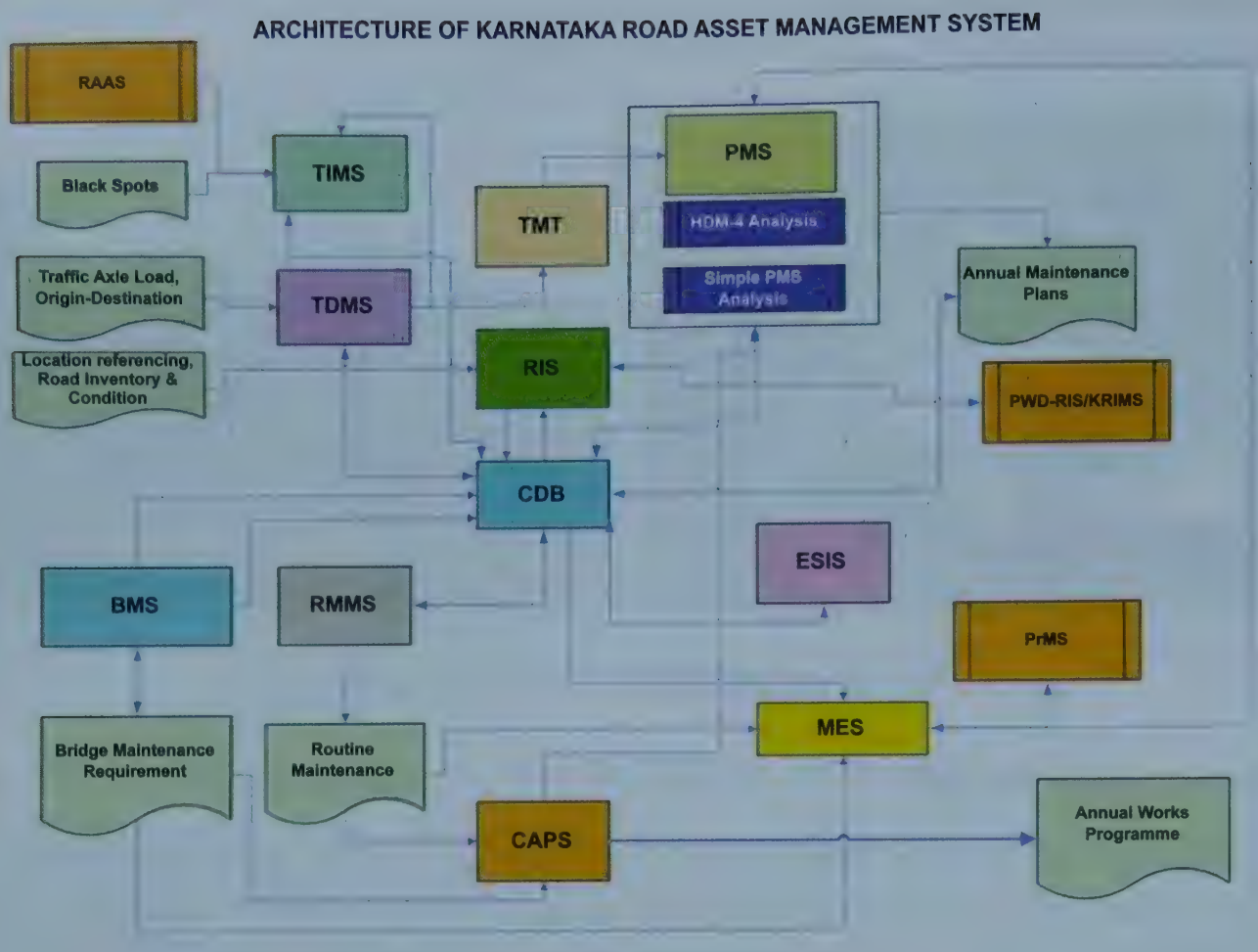

Fig. B.16 KRAMS System Architecture

The following eleven (11) modules are included in KRAMS:

1. Central Data Base (CDB): A central repository system for non-spatial attribute data interfacing with RIS. The historical information is stored and managed in the CDB.
2. Traffic Data Management System (TDMS): TDMS stores, processes, analyses and reports related to traffic volume, axle load and origin and destination data. The outputs from the TDMS, in terms of traffic and vehicle related information are finalised considering the requirements of HDM-4 and linked with PMS. TDMS is also interfaced with TMT.
3. Transport Modelling Tool (TMT): This is a third party application dealing with road network development master plan and interfaced with COTS HIMS. It takes relevant inputs from CDS, TDMS and TIMS to predict future changes in the pattern of traffic distribution over the Karnataka State Highway inter-urban road network resulting from changes in infrastructure and through economic sectoral land use developments etc. The TMT links with KRAMS specifically in the sense of identifying new or upgraded road links on the basis of forecast changes/upgrades in transport infrastructure, modes and land use patterns and thereby supply future year traffic volume information to KRAMS/HDM-4.
4. Pavement Management System (PMS): PMS, a major decision support system intended for management of periodic and capital road work activities, such as widening, reconstruction and strengthening, using HDM-4 and decision tree based approach. HDM-4 is used for the Core Road Network of state roads, whereas a decision tree is expected to be used for the rest of the road network. This application will cover preservation of the existing road network as well as expansion which may cover new links, multi-laning, or capacity increase. The engineering and economic analytical tools available within HDM-4 is providing deterioration prediction.

5. Bridge Management System (BMS): The BMS is an integral part of the KRAMS and is used to store inventory data on minor and major bridges and other structures from information collected through routine and special inspections. All structures types having a span greater than 6.0 m such as major and minor Bridges, Fly overs, ROB, RUB etc, and other cross drainage structures having spans less than 6.0m, such as box culverts and others requiring structural assessment are included in the BMS. After a thorough review of the available bridge maintenance planning methods, Bridge Condition Index (BCI) approach is adopted. The maintenance intervention is determined on the basis of the BCI.

6. Routine Maintenance Management System (RMMS): The RMMS determines routine maintenance requirements of the road network, with periodicity including pre and post monsoon activities, for sections not receiving periodic maintenance or improvements in that year. RMMS deals with assets such as culverts, traffic signs, km stones, shoulders and vegetation clearance etc.

7. Traffic Incident (Crash) Management System (TIMS): The TIMS records data related to Killed and Serious Injury (KSI) accidents (crashes) and road safety features (such as objects in the safety clear zone) with exact location (linear and/or geo-referencing) along with distance etc. from carriageway. This System enables to enter and maintain road accident data, suitable analysis tools and a reporting system for black spot and network level investigations. KSHIP has developed Road Accident and Analysis System (RAAS). TIMS is developed to interface with RAAS to exchange information.

8. Environment and Social Information System (ESIS): ESIS provides an assessment of the social and environmental impact criteria which are critical to the development and management of the road asset. Levels of importance for each criteria or group of criteria is established and these are assessed in relation to road network or project development. The ESIS stores the environment and social information data used for decision-making to plan and implement the improvement, up-gradation and maintenance of roads.

9. Monitoring and Evaluation System (MES): PWP & ITWD operates a Progress Monitoring System (PrMS) which stores and manages data related to roads and buildings works. The MES has the capability of monitoring physical and financial progress of civil works, goods and consultancy services in the department. MES is interfaced with the existing system (PrMS) to avoid duplication. All required data for MES are accessed from the existing Progress Monitoring System. The MES provides input data to the Pavement Management System (PMS) in terms of roads under construction/maintenance or construction/maintenance likely to be initiated. Based on this information, the PMS does not include those sections in the analysis.

10. Cross Asset Prioritisation System (CAPS): CAPS combines the maintenance needs determined from PMS for pavements, BMS for bridges and culverts, RMMS for routine maintenance and TIMS for rectification of black spots and other accidents to prepare a combined and prioritized AWP. User defined weightage factors, which can be modified each year by PWP & ITWD, are used to define the priority of maintenance works.

11. Administrative Modules (AM): KPRAMC has a comprehensive and integrated User Administration, Data Migration and Management, Data Dictionary and CDB Health, CDB Connection Management, Error Handling and Support Management functionality.

A typical screen of the KRAMS System Architecture is given in **Fig. B.17** below:

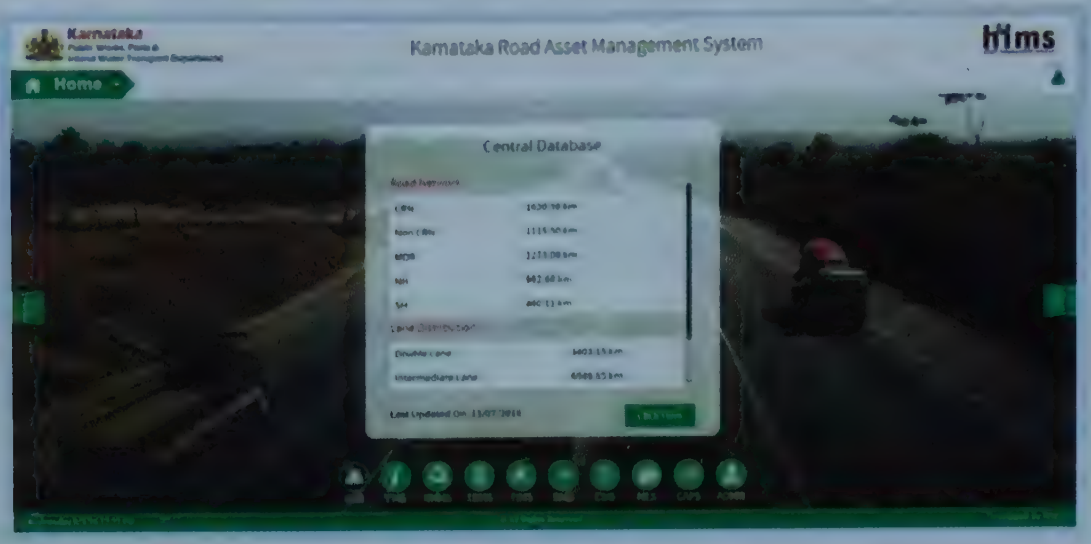

Fig. B.17 Typical KRAMS Screen

Road Information System (RIS): PWP & ITWD has been using a desktop and a web based RIS for more than a decade. Desktop version was used for location referencing functions and historical data with internal access to PWP & ITWD. Web based version is used for the public access with summarised information and GIS functionality. Given its long history, PWP & ITWD decided to continue to use the web based RIS with some improvements and including location referencing functions. Now RIS is only available through the web based interface. The architecture of WebRIS is given in **Fig. B.18** below.

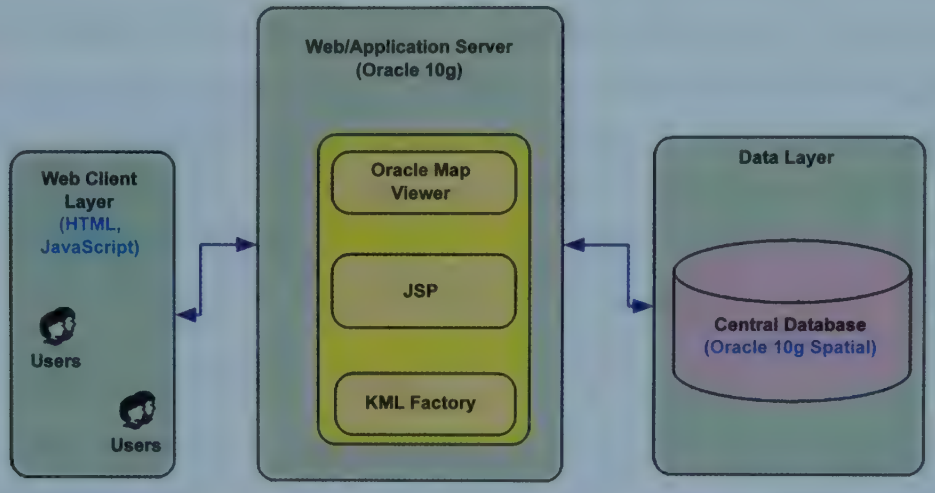

Fig. B.18 WebRIS Architecture

After a thorough and careful analysis PRAMC hosted the COTS part of the KRAMS in-house. PRAMC established a Data center with world class servers and network equipment to support its IT needs. DC has huge storage space to manage data such as videos, images, large size data files, engineering drawings and GIS maps. It is empowered with high bandwidth secured internet connections and thereby providing access to all the stake holders.

PWP & ITWD was finalizing the road maintenance works using more traditional and adhoc analysis. KRAMS was introduced with an objective of adopting more scientific approach towards determining the maintenance and improvement requirements of State road network. Considering the success of KRAMS, the Government of Karnataka issued an order (GO) mandating to prepare the prioritised list of maintenance of roads from KRAMS for next five years to receive road maintenance funds. PRAMC prepared the AWP for 2017-18 and 2018-19 and committed to prepare future AWPs using KRAMS. PRAMC is preparing detailed project reports and implementing rectification measures of identified black spots. PRAMC trained around 500 Engineers of PWP & IWTD in data collection, data processing in KRAMS and preparation of AWPs.

OVERVIEW OF NHAI ROAD ASSET MANAGEMENT SYSTEM (RAMS)

National Highways in India have a total length of over 1,00,000 km and serve as the arterial road network of the country. The development of National Highways is the responsibility of the Ministry of Road Transport and Highways (MoRTH), and its associated executing organisations; National Highways Authority of India (NHAI), NHIDCL, State PWDs and Border Roads Organisation (BRO).

In the past, both NHAI and MoRTH have developed Road Management Systems (RMS) to manage their respective National Highways. In 2005-06, NHAI developed a GIS and web-based system called "Road Information System" (RIS) for operation and maintenance, strategic planning and decision-making relating to the National Highways entrusted to it. The RIS contained static and dynamic inventory data on National Highways stretches on Golden Quadrilateral (GQ), National Highways connecting Delhi-Mumbai-Chennai-Kolkata-Delhi, obtained from primary field surveys during 2003 (1,159 km), plus static data (from secondary source) on further 4,700 km of NH falling on GQ and 5,000 km of North South (NS) and East West (EW) corridors obtained from Detailed Project Reports. Thus, the RIS was populated with data from Primary and Secondary sources for an approximate length of 11,000 km. MoRTH developed National Highways Information System (NHIS) through Central Road Research Institute (CRRI) between 2006 and 2010. NHIS was GIS based and provided options for storing data on road inventory, traffic, pavement structure and history, pavement condition and other road features. The database was designed to support the use of HDM-4 as a primary analysis tool to produce a long-term strategic road network plan and rolling multi-year works programmes. NHIS was developed for National Highways under the jurisdiction of MoRTH. Both RIS and NHIS couldn't be implemented due to issues related to institutional aspects.

NH RAMS was developed and handed over to NHAI in 2017 with the following modules:

- Location Reference Management System (LRMS): Location Reference Management System (LRMS) was developed to maintain centralised location referencing for RAMS. The LRMS formed the core of the RAMS, a system that defined and enforced the proper referencing conventions of the roads and associated assets. RAMS has facility for linear and geo-referencing (spatial) features. The primary functions of Location Reference Management (LRM) are:
  - to enter, validate and store location referencing data (Road, Link, Node, LRP etc.),
  - to manage location referencing data for all modules of RAMS,
  - to edit, delete road/links/sections,
  - to modify location referencing data and trigger relevant changes in other modules of RAMS,
  - to maintain historical changes in the road network.
- Road Information System (RIS): Asset Management System (AMS) or Road Information System (RIS) was developed to store assets inventory, condition and other relevant information. RIS provides information to other sub systems (modules) within RAMS. RIS has the following key functions:
  - Store and manage inventory and condition data,

- Store and manage spatial data,
- Store and manage pavement strength data;
- Manage historical data and identify latest data;
- Facilities for adhoc and statistical queries;
- GIS platform to view network and other attribute data;
- Summarised (and current) attribute data to other modules such as PMS, BIS, AIS etc.;
- Thematic maps, tabular reports and charts.

- Pavement Management System (PMS): The major function of the Pavement Management System (Planning and Budgeting tool) is to determine the maintenance needs of the National Highways, in terms of Preservation (what is the appropriate periodic maintenance strategy to preserve the road asset), Improvement (what maintenance treatments are required for pavements whose condition requires a major treatment before periodic maintenance can be applied) and Capacity Augmentation (what capacity is required for current and future traffic loading). HDM-4 analysis engine, based on sound engineering and economic priority principles, is adopted for undertaking both strategic and project level analyses. Given the past experience, two sub systems under Pavement Management System are included:
  - Simple Decision Tree or Multi Criteria Analysis approach for Programme level analysis (Renewals, Rehabilitation and Widening);
  - HDM-4 analysis for Strategy and Project Level Analysis.
- Bridge Information System (BIS): The main purpose of the Bridge Information System (BIS) is to provide information on inventory and condition of bridges and culverts, to facilitate identification of bridge repairs and improvements in a systematic way, enabling early identification of deficiencies and applying preventive maintenance. BIS stores bridge inventory and condition data and source other requisite data from other sub systems, i.e. road inventory data and traffic data etc. MoRTH developed Indian Bridge Management System (IBMS) for all Bridges on National Highways. IT is intended to interface BIS with IBMS and source relevant information.
- Traffic Information System (TIS): The main purpose of the Traffic Information System (TIS) is to store classified traffic volume count and axle load data along with other necessary information, i.e. vehicle fleet characteristic, vehicle types, traffic count locations. Traffic Management System (TMS), which stores and manages traffic volume data for all predefined volume count locations is available with NHAI. These are primarily established close to the Toll Plazas where toll is collected from road users. It is intended that TIS is interfaced with TMS.
- Accident Information System (AIS): The use of Geographic Information Systems (GIS) in road safety analysis has increased rapidly in recent years. A major reason for this growing interest is the fact that spatial factors such as land use, population density, population distribution, socio-economic factors as well as environmental factors have strong influences on accident occurrence in addition to the commonly known geometric design elements of roadways and road users' behaviour. The key

purpose of this sub system will be to manage, analyse and report on accident data for purposes of identifying black spots.

- Environmental Information System (EIS): The main purpose of the Environmental Information System (EIS) is to store environment, social and land use along with other necessary information. EIS has the following key functionality:
  - Store environment related information (linear and spatial location details),
  - Identify road sections with environmental and social constraints,
  - Display bottlenecks and constraints on the embedded GIS map.
- Geographical Information System (GIS): This module provides GIS platform for viewing, managing and sourcing information to help make decisions on the road maintenance planning.
- System Administration Module (SAM): This will include User Administration module, Batch Process Management tools, Database Connectivity tools etc. This determines the user's access level and road network area using their Login credentials. System backup and routine maintenance facilities are included in this subsystem.

NHAI adopted a bespoke development approach for design and development of RAMS. The technical architecture of the RAMS is given in **Fig. B.19** below.

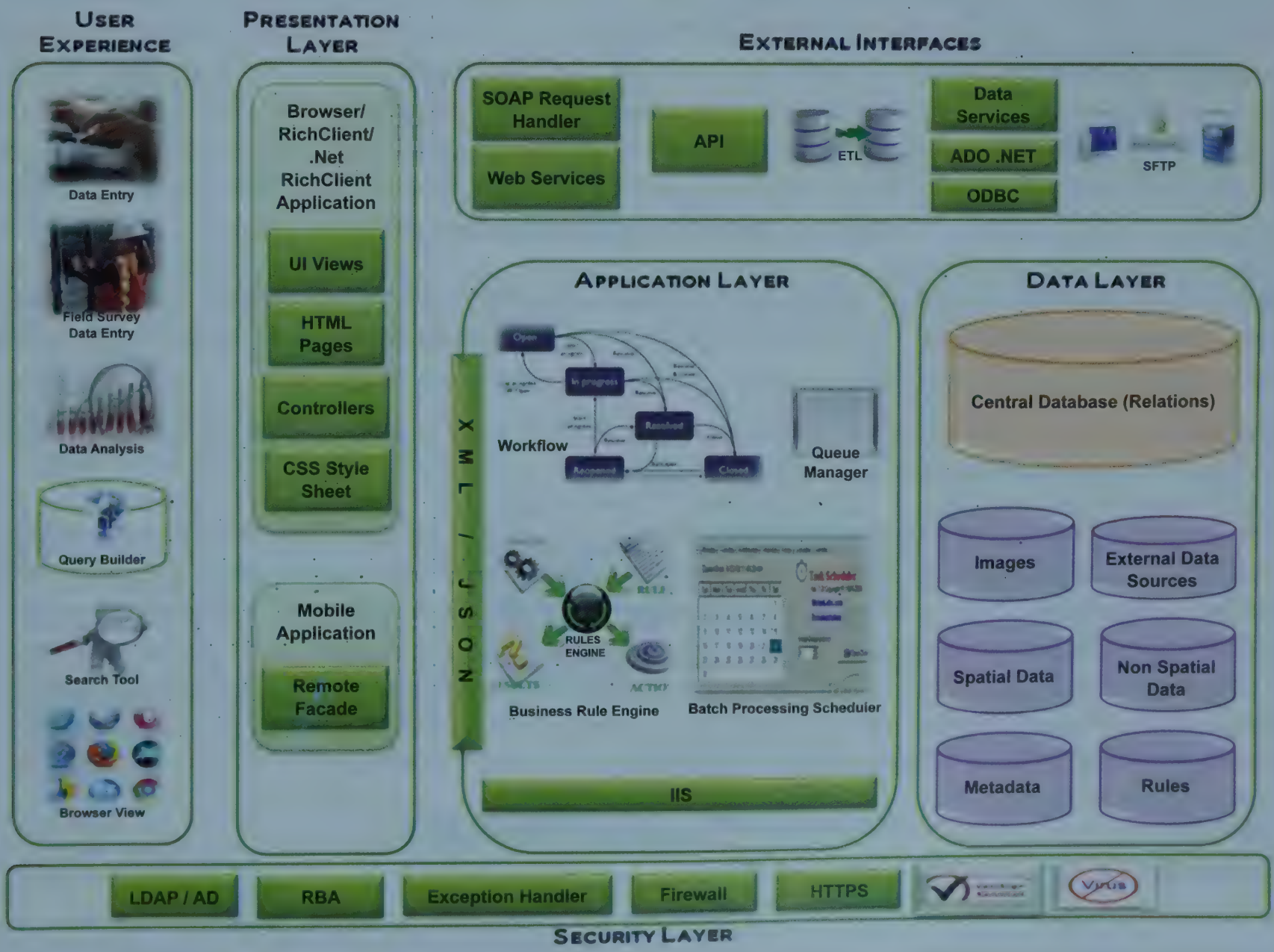

Fig. B.19 RAMS Technical Architecture

The physical architecture is given in **Fig. B.20** below:

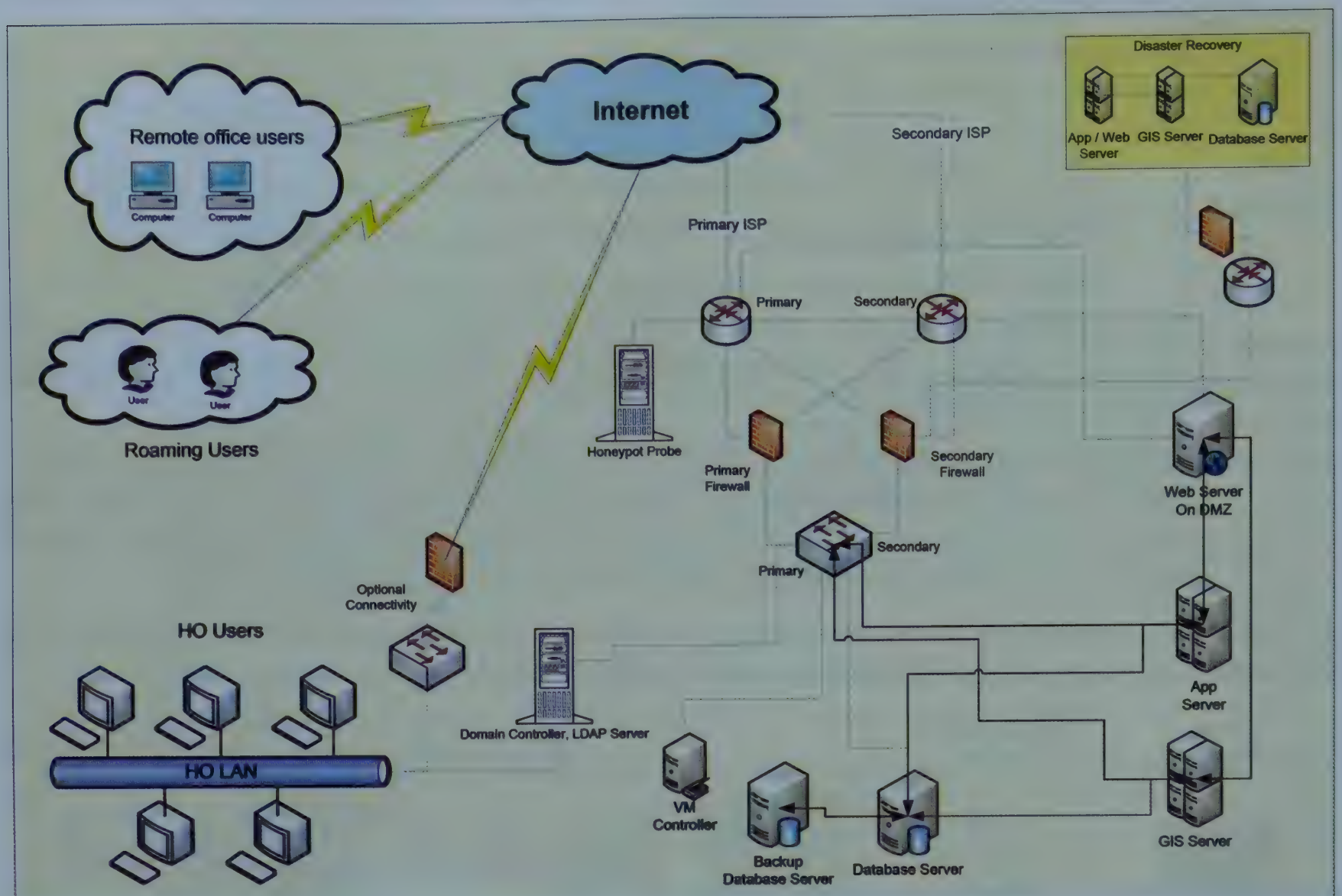

Fig. B.20 RAMS Physical Architecture

The Closed Source Software (CSS) was selected for development of RAMS after thorough and detailed discussions on Open Source Software (OSS) and Closed Source Software (CSS) between MoRTH, NHAI and NIC.

RAMS was hosted with NIC on its Cloud Server initially. It was moved to ERP Consultant Server who will maintain and provide support for 7 years.

The cost of data collection tends to be the largest component of managing and running RAMS. Further, the direct benefit of frequent (or regular) collection of information shall be justified for continual allocation of funds for collection of information. Hence, the data requirements including method and frequency of collection were chosen after thorough review of all plausible options to provide the anticipated sustainability to the RAMS. The collection of data items suggested for the purpose of development and subsequent update of the RAMS is given below. All data items are recommended to be collected in the base year.

Data Item	**Selection**	**Method**
Annually		
Surface distresses #	Mandatory	Windshield/Video logging
Roughness and Rut depth	Mandatory	Automated
Shoulder and Drain condition	Mandatory	Windshield

Data Item	Selection	Method
Traffic volume and Axle loads	Mandatory	Manual/ATCC/Transcription
Accidents	Mandatory	Transcription
Other condition	Optional	Windshield/Video logging
Structures condition	Mandatory	Visual
ROW video	Mandatory	Automated
Every 5 Years		
Network*	Mandatory	Automated
Road Inventory*	Mandatory	Windshield/Video logging/Transcription
Pavement deflection, Composition and History	Mandatory	Automated/Transcription
Structures inventory	Mandatory	Visual

Recommended to review the method at a later date to explore the possibility of using automated equipment measurements.

* Validation survey suggested every 5th year subject to availability of funds and considering the reliability of the data obtained from other sources.

It is ideal to have the unified and consistent data readily available over the entire National Highway network in India. However, the cost of data collection for over 1,00,000 km is expensive and resource intensive. However, it must be considered that several streches of the National Highways are developed and managed using private funds (Concessionaries or Operators) where the respective asset owner, NHAI or MORTH has limited role in road maintenance planning, except enforcing the provisions stipulated in the Concession Agreement. NHAI or MORTH is not directly responsible for upkeep of the road sections, however responsible for enforcing and monitoring the Concessionaries or Contractors obligations. Therefore, data over these road sections need not necessarily be of equal frequency and comparable precision as that of the remaining roads, which uses public funds. The appropriate data requirements and strategy for their collection specific to each type of network (public funded and private funded) were created specifically. The effectiveness and sustainability of RAMS was given due importance while developing the data collection strategy. Given that most of the required data not available with MORTH, it is recommended to collect all data mentioned above for public funded roads. Although there are some issues in reconciliation associated with the data proposed to be obtained from the BOT Concessionaries and OMT Operators, but given the limited role played by NHAI/MoRTH in decision making or managing these privately funded roads, annual data collection is not recommended. It is suggested to develop some specific and simplified data formats to obtain requisite data for implementation of RAMS to privately funded roads.

The following method or equipment used to collect data over 3,000 km to develop RAMS.

Date Item	Equipment/Method	Module/Source
Location Reference	ROMDAS NSV	HRDMI, Keyboards and Trimble SPS 461 or equivalent
Road Inventory	ROMDAS NSV	Keyboard
Visual condition	ROMDAS NSV	Keyboard

Date Item	Equipment/Method	Module/Source
Roughness	ROMDAS NSV	Dual wheel path Laser profilometer
Rut depth	ROMDAS NSV	Multi point Lasers Profilometer
Bridge Inventory	Visual	Aided by tape measure and still camera
Bridge Condition	Visual	Aided by tape measure and still camera
Culvert Inventory	Visual	Aided by tape measure and still camera
Culvert Condition	Visual	Aided by tape measure and still camera
Pavement Deflection (Strength)	FWD	Trailer mounted single mass
Pavement History	Transcription	NHAI, MORTH, PIUs, CMUs etc
Axle Load	Static Axle load pads	Portable pads
ROW (Front view) Video	ROMDAS NSV	HD Video
Traffic Volume Counts	Manual	Obtain from IHMCL
Road Accident	Transcription	Obtain from Secondary Sources

The location of the inventory features can be obtained through the chainage measurement (from DMI) and GPS coordinates (from DGPS) as shown below in **Fig. B.21**.

Fig. B.21 Typical View of Survey Vehicle

It was proposed to establish a dedicated RAMS Cell in NHAI or MORTH to take over the further implementation and continual operation of the RAMS. It is preferred that RAMS Cell be established on full-time basis and as an independent unit. RAMS Cell will bring all initiatives related to data collection, data management, and information sharing on National Highways under one umbrella including annual data collection by NH Divisions of State PWDs, Concessionaries, Contractors and Consultants. The main objective of the RAMS Cell is to operate, maintain, update and upgrade RAMS system developed for all National Highways in India, with the following key functions:

- To plan, monitor and manage annual data collection of National Highways,
- To process, manage and perform quality assurance of the data collected,
- To load processed data into RAMS,
- To operate RAMS on daily basis,
- To provide or answer daily or ad hoc enquiries,
- To identify potential improvement and up-gradation of projects on PPP/EPC basis or otherwise,
- To prepare annual maintenance needs and related budget for public funded roads,
- To monitor Concessionaire obligations in terms of key performance indicators for privately funded roads,
- To impart training and technology transfer on operation of RAMS,
- To provide helpdesk support to RAMS users,
- To manage and monitor external consultants working on RAMS.

The organisation structure as given in **Fig. B.22** is finalised in consultation with stakeholders:

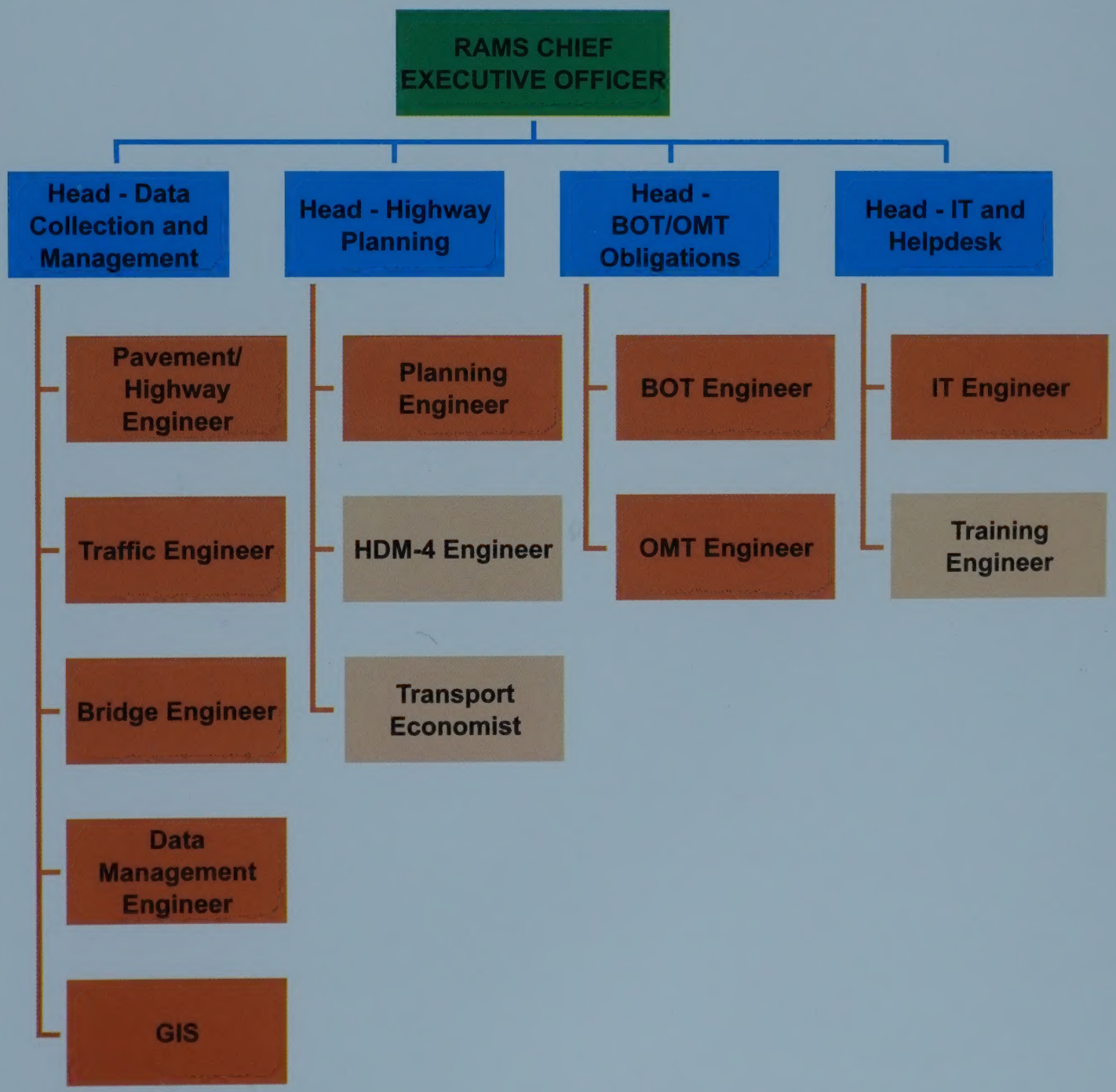

Fig. B.22 RAMS Cell Proposed Organisation Structure

Both options, deputing internal resources or outsourcing model were discussed with senior management of NHAI and MORTH. It is felt that NHAI or MORTH may not be able to depute such high rank staff on full time basis. Therefore, it was decided to adopt outsource model initially for a few years (say 3 to 5 years) and managed by NHAI. The data will be collected through outsourcing model by engaging experienced Consultant.

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)

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